

COMBUSTION

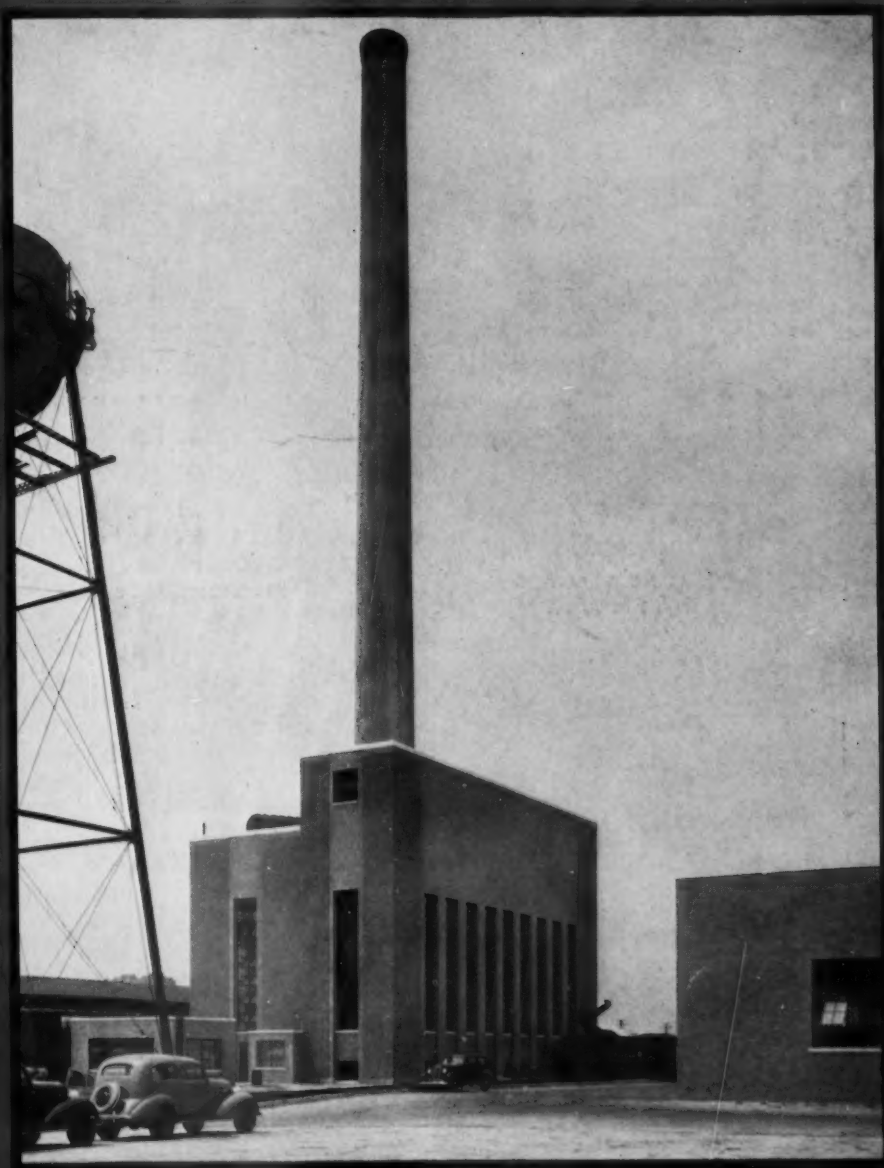
DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

V. 6, No. 12

JUNE, 1935

Index

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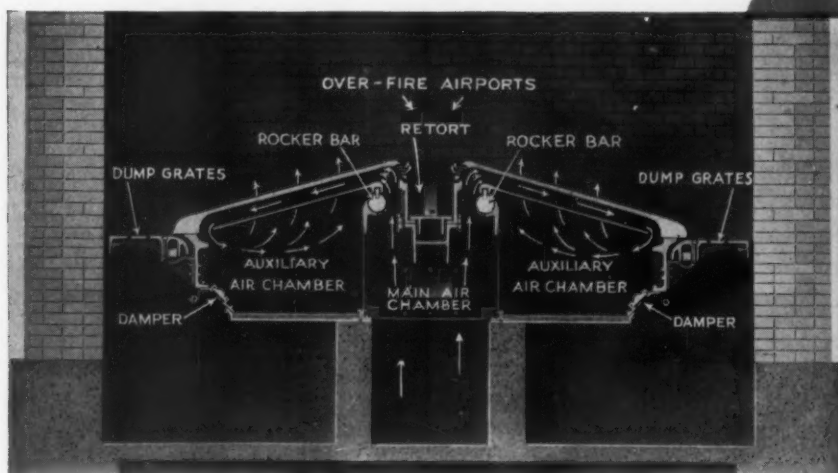


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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME SIX

NUMBER TWELVE

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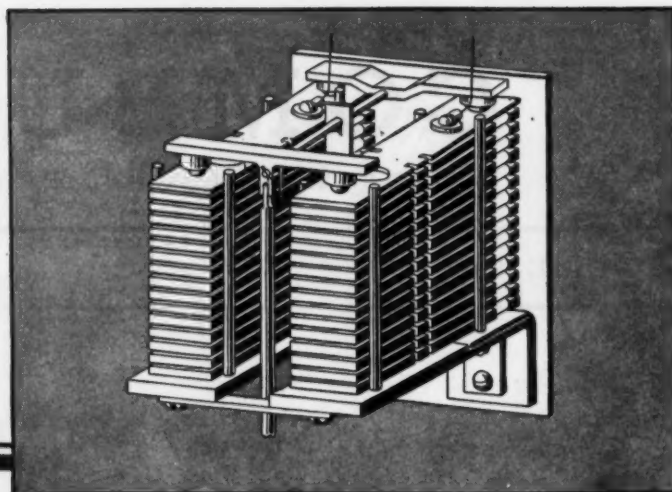
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Combustion is published monthly by Combustion Publishing Company, Inc., a subsidiary of Combustion Engineering Company, Inc., 200 Madison Avenue, New York. Frederic A. Schaff, President; Charles McDonough, Vice-President; H. H. Berry, Treasurer; G. W. Grove, Secretary. Subscriptions, including postage, United States, \$2.00, Great Britain, \$2.50 a year, Canada, \$3.00 (includes Canadian Tax). Other countries, \$3.00. Single copies: 25 cents. Copyright, 1935, by Combustion Publishing Company, Inc. Printed in U.S.A. Publication office, 200 Madison Avenue, New York. Issued the middle of the month of publication.

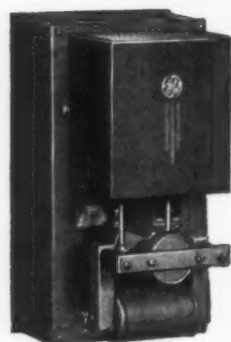
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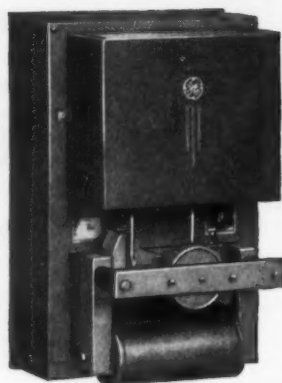
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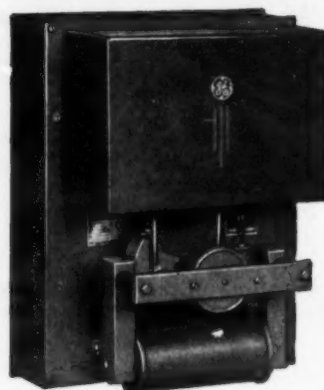
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EDITORIAL

Looking Ahead in Central-Station Practice

In this issue there appears the first of two articles by Professor Christie discussing broadly the factors which are most likely to influence new capacity that must be installed, sooner or later, to meet most economically increased central-station load. His second article, to appear next month, will take up in greater detail certain features of station design that are most likely to meet the future requirements.

Among the various points considered, one deserves special attention. This is the conclusion that, with present fuel costs, modernization of an old central-station plant may not always be warranted, but increased plant efficiency through modernization, coupled with increased capacity, will usually warrant the necessary expenditure. That is, the installation of a high-pressure boiler and turbine exhausting to the existing low-pressure system will not only greatly lower the station heat rate but will provide additional capacity at relatively small unit cost. An outstanding example of such an installation is the Burlington Station in New Jersey.

While unanimity of opinion is lacking as to the present need for additional capacity for the central-station industry as a whole, largely because of diverse local conditions, it is quite evident that an early return of normal industrial load, in addition to the present increased domestic load, would find some sections in need of additional capacity. Therefore, the time is opportune to consider carefully the designs that will best meet the probable conditions. In this connection, the opinions of Professor Christie, who has long enjoyed the position of an impartial observer in close contact with central-station views and practice, will receive thoughtful consideration by those upon whom will rest the responsibility for station design.

Flexibility in Fuel Burning to Meet Changing Prices

Prior to the recent Supreme Court decision, opinion within the coal industry was divided between those who favored the Guffey Bill for stabilization of the industry and those who felt that operation under the bituminous coal code was adequate to meet the situation. However, according to Washington observers, the decision against the NRA appears to have greatly strengthened the proponents of special coal legislation, which many contend will result ultimately in higher coal prices.

Fuel oil prices advanced over a year ago to the point where coal enjoyed a marked advantage. An increase in coal prices would again place the two fuels in competition in many localities.

With this potential situation in view it would seem wise for those who are contemplating the installation of

pulverized coal to put in combination burners. A furnace designed for burning pulverized coal is equally well adapted to burning fuel oil, and with equipment installed for burning either fuel a change over can be made in a few minutes. The additional initial cost is relatively small and the flexibility of such an arrangement provides the plant owner with a very effective means of taking full advantage of changing conditions in the fuel market.

Will Many of the Younger Engineers Lack Experience

This month a new batch of engineering graduates will be turned out by the various technical schools. Their prospect of obtaining employment along engineering lines is somewhat brighter than was the lot of graduates during the past two or three years, although many of the large companies have not resumed the former practice of each year taking a certain number of young engineers into their organizations for training in their respective lines.

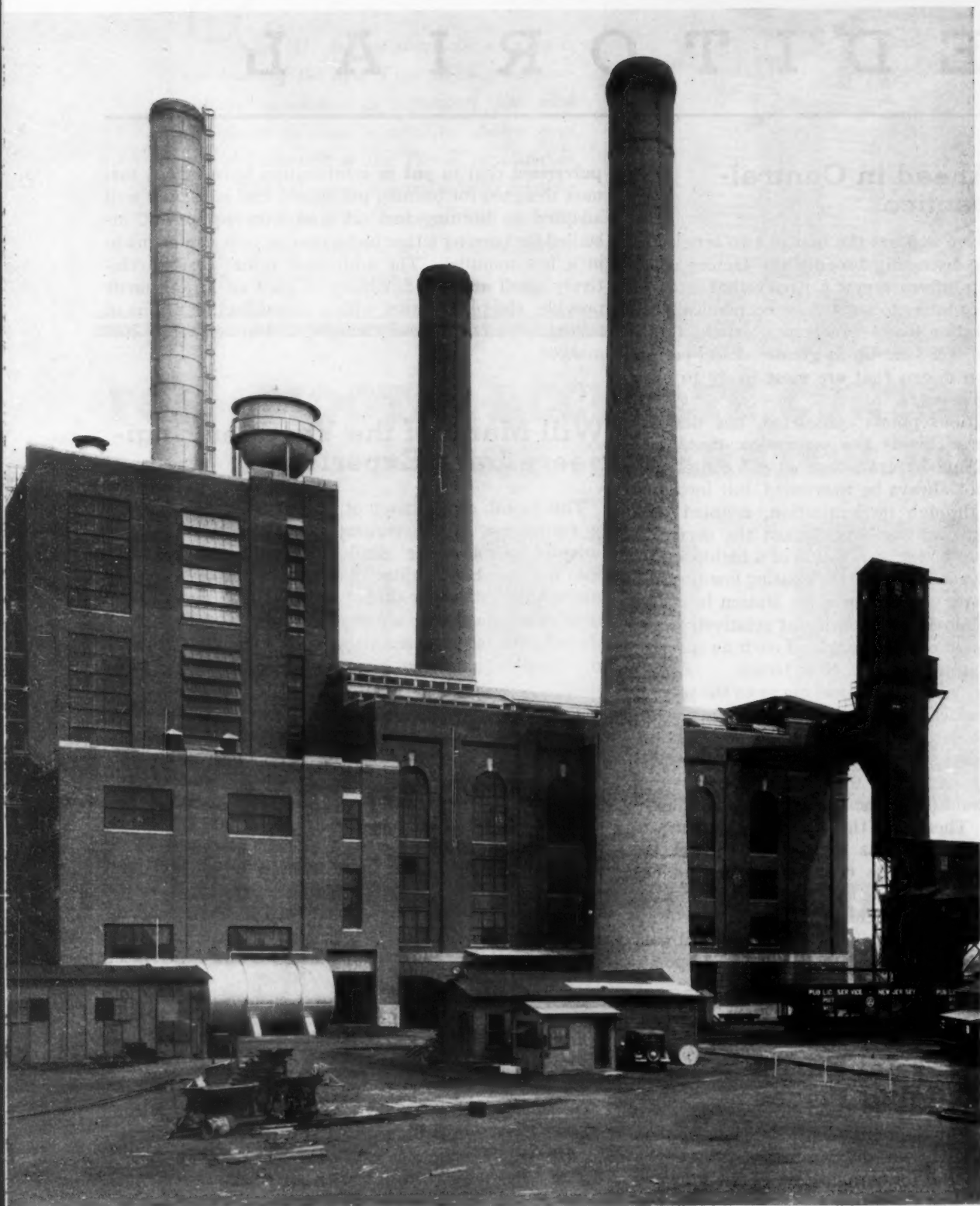
The diversion of many of these technically trained men into lines other than engineering may be beneficial to the industries concerned but its effect on strictly engineering industries will not be felt until the capital goods industries have again resumed normal operations. For a while the demand will be met by engineers now out of employment or on emergency work but as time goes on the ranks will need to be supplemented by younger men with some practical experience in engineering work. The gap of the past few years is then likely to be felt.

The effect may be to place a premium on the services of those with the requisite qualifications and experience.

Performance of British Power Stations

On page 36 will be found a tabulation of the performance of forty-two British power stations for 1934 as reported by the Electricity Commission. Barking "B" Station which tops the list with an efficiency of 27.95 per cent and Battersea which has the lowest coal consumption, namely 1.06 pounds per kilowatt-hour, closely approach some of our most efficient stations. While the average of 1.58 pounds per kilowatt-hour for all the British central stations is still some points above the average of 1.45 for this country, last year saw an improvement of 0.07 lb for the British stations as compared with 0.01 lb for our own.

So many factors enter into the problem that comparisons are likely to be misleading but it is significant that British power station practice is now pushing to the front rank.



Burlington Station of the Public Service Electric and Gas Company (New Jersey) an outstanding example of a high-pressure boiler and turbine superimposed on the old low-pressure plant.

When the Power Load Grows

By A. G. CHRISTIE

Professor of Mechanical Engineering
The Johns Hopkins University, Baltimore, Md.

General problems connected with the future growth of the power load and means for meeting such an increase are discussed in the present article. Part II, which will appear in the July issue, will take up details of plant design and comment upon possible developments in equipment.

PART I

DURING a forced convalescence, the writer interested himself with planning the modernization of central station plants with the design of which he has been associated, and also with picturing the design of new plants to utilize the latest machinery available. These conceptions, while incomplete and with much detail lacking, suggested the idea that many of these problems deserve consideration by other engineers in order that they may be ready to meet situations that may develop when the power load grows again. These comments will not be as specific and detailed as Gaffert's discussion of "High Pressure Steam and Binary Cycles," *TRANS. A.S.M.E.* Oct. 1934, nor as in Iddles' "Planning New Capacity," *Elec. World*, Apr. 13, 1935, and other similar discussions.

Economic Factors

One cannot be other than an optimist on the future of the United States. Soon the common sense of our people will prevail and the normal prosperity of the country will return. Then power loads will grow rapidly and engineers will find themselves faced with new problems in providing for this growth. There are many indications that the turn toward prosperity has already occurred. For instance, power loads have shown moderate gains over former years. Hence, it is pertinent to consider what should be done when the power load starts to grow more rapidly.

Engineers cannot overlook the changed economic status of central station projects. The hostile attitude of the Federal Government toward utilities, increased taxes, the demand by customers for decreased rates for service and the consequent poor market for utility securities, will necessitate more serious consideration of costs and particularly of investment than was customary in the past. One can say that costs will dominate future plant design and rehabilitation.

What about the probable rate of load growth? This, of course, cannot be predicted with any exactness. The domestic load is growing steadily and will grow even more rapidly with lowered rates. This load is becoming more diversified over the hours of the day than when lighting was the main service. The shorter hours of labor have also affected the peak load that used to come at six o'clock in the evening. It is quite possible that daily peaks in cities with heavy industrial loads may hereafter occur in the morning hours. A few years ago,

the writer made a study of the growth of load following 1918 in certain cities in Western Canada and in England. The total load on each utility grew very rapidly after the war adjustment, but the most surprising fact was that this growth soon restored the load about to the projected curve of normal growth before the war. In other words, the electrical load, when given an economic opportunity, compensated for losses during the four years of war and the depression years in Canada and England directly following the war.

Can a similar growth be expected in the United States? If normal prosperity returns, such increases will probably occur. Of course, one must concede that our use of electricity is much more highly developed than in England in 1920, but no more so than in the Canadian cities. This development should be given consideration in projected load studies from pre-depression years. The economies forced on manufacturers by the depression and by N.R.A. have induced the replacement of high cost labor by machinery. This will lead to increased power consumption later. Hence, one may expect a substantial and rapid growth of power load as well as of domestic load when economic conditions improve.

These considerations indicate that a substantial increase in generating capacity must shortly be provided by certain utilities with small spare capacity, and that this new capacity must be installed at low cost and designed to give the greatest possible return per dollar invested.

In the past, engineers have been accused of building expensive plants to secure the highest thermal efficiency. Someone had to pioneer in high-pressure and high-temperature equipment and these developments were sometimes expensive. Their experiences have resulted in substantial advances in the art of station design and others have benefited from their pioneer work. Later designs of high-pressure and high-temperature plants have cost little if any more than low-pressure plants. The cost of future equipment, its probable life, its overall station economy, and probable fuel prices will govern the final decisions on new plant extensions.

Size of Plant

Shall a new plant be one of the so-called "superpower" plants with machines of great capacity and with a large total output? Or is it preferable to build a number of medium sized plants, spread over the territory served and

close to load centers? This decision depends on the economics of the situation. The subject has been discussed by other writers and only a few comments will be presented. One must balance the economies of distribution from a number of smaller plants on a power system against the savings from generation in the large station and distribution therefrom. Reliability may favor the smaller stations. First and operating costs will be less in the large station. Transmission losses will be greater with the large station. The problem becomes a local one and no set solution can be stated for all cases.

The decision on plant size is also affected by problems of inter-connection and reserve. If a portion of the new station can serve as a reserve to an inter-connected system and its cost shared by all other connecting companies, a larger installed capacity may be warranted than would be the case for a single system.

Inter-connection introduces other cost problems. In an inter-connected system the plant with the lowest increment power cost, with consideration of transmission losses, should be given the base loads of all inter-connected companies. Everyone likes to see his new station fully loaded. Hence, there is a tendency to design a station with the lowest thermal rate of the inter-connected system for, in general, increment cost is fuel cost. However, there is no economy in securing this low thermal rate at the expense of unduly increased first cost and fixed charges. There is no discredit attached to a new station that may only serve during peak load and as reserve for the inter-connected system, if this station provides these services at the lowest cost—both investment and operating. The writer has urged the study of peak load plants as possible means for reducing power costs and has planned several such plants. Such a plant may operate only a few hundred hours per year and serve as reserve for the remainder of the time. The sole object of each new plant should be to provide the desired service with reliability at the lowest possible total cost.

The utilization of secondary and surplus power also must be considered. For instance, in times of high water, secondary hydro power may be had at low increment cost of plant expansion to develop this power. Again, surplus power from certain industries within the system's area, may be available upon a firm power or dump power basis. This, if furnished at a low increment cost, should also be utilized. Finally, there are sometimes installed in industrial plants, certain units that could be called on for peak or emergency service. Consideration must be given to the effect of business cycles on the availability of industrial generating equipment. In dull times this industrial plant may not be kept in active reserve. Such reserve plant, when available, lessens central-station investment and thus has an asset value to the system as a whole.

Operating Conditions

The plant designer now has a wide range of operating conditions from which to choose. He may select any boiler pressure up to 3200 lb per sq in. and any temperature up to 1000 F. Some of these pressures and temperatures are still in development stages but commercial plants have been operated at these conditions and suitable equipment is now offered by builders.

Steam pressures and temperatures should be chosen

so that exhaust conditions with 29 in. of vacuum will vary from 10 to 12 per cent moisture content in the steam. With high tip speeds on the blades of the last rows, this appears to be about the maximum range for moisture if rapid blade erosion is to be avoided. Such exhaust conditions can be secured by proper selection of initial steam pressures and temperatures or by interstage reheating of the steam.

Studies at several operating conditions will have to be made and estimates prepared of first cost and operating costs under the expected load conditions before a decision can be made. No serious trouble has developed in high pressure stations and one may confidently expect new stations to be built for higher pressures than has been past practice. Boiler and turbines have been designed for some of these higher pressures and hence development charges on such equipment should be moderate.

While the stations employing higher pressures have operated quite satisfactorily, there is a tendency to caution as to increasing temperature. In general, increased steam temperature tends to be the cheapest means of achieving higher thermal efficiency as only that small portion of the plant from the superheater inlet to the intermediate pressure section of the turbine is affected by the increased temperatures. Due to less steam consumption with increased superheat, boiler, heaters and condenser surfaces can be decreased and their cost lessened.

Many of the earlier stations designed for the higher pressures, were equipped with live steam or gas reheaters. These increased first cost, made the stations more complicated and limited the flexibility of operation of the unit. New stations will, in all probability, have sufficiently high initial temperatures at the operating pressure that reheating will be unnecessary. Initial steam temperatures of 850 and 900 F are already used in new stations. Turbine builders are prepared to furnish units for these temperatures. The use of such high temperatures with high steam pressure will simplify the lay-out, lower first cost and decrease operating problems as compared to reheating.

An error frequently made by designers has been an over-estimation of the useful life and output of a new unit, particularly one on a growing system. The new equipment for the first few years of its life, is given the base load of the system and, under these conditions, it provides excellent performance records. When the next unit is added, it usually embodies improvements due to progress in the art, and, as a result, the new unit in turn, carries the base load. The older unit is then relegated to a lower use factor. With the addition of still more units, the first unit shortly serves for peak load service only. The older unit may even be replaced by more economical equipment though, as a piece of machinery, it still is capable of much useful service.

Other contingencies may lead to the same result, namely, a small average use factor over the total life of the unit. For instance, one comparatively new station with creditable thermal performance, now provides peak load and stand-by service only through a system inter-connection with a new water power plant and also with another new station with a lower increment rate. Designers must therefore give careful consideration to the probable average use factor of the plant throughout its whole life and in preparing this estimate they must

consider the effects of further developments in the art of power station design and inter-connections.

There appears to be radical differences in the practice of various Government and Regulating Commissions regarding methods of providing for retirement of plant. Some utilities either have neglected to provide adequate depreciation reserves or are prevented from making necessary appropriations for depreciation. Proper depreciation and retirement should be provided so that lower rates are possible through lessened investment values on the books of the utility. A standard depreciation and retirement policy would be an important contributing factor in straightening out the present difficulties of the utilities and in stabilizing rates.

Further Thermal Advances Possible

It has been suggested that recent improvements in boilers, turbines, condensers and auxiliary apparatus leave little for further development. While the operation of these machines has been greatly improved and, in the case of certain ones, is approaching the economic limit of development, the writer firmly believes that advances in thermal performance may still be attained through the use of still higher pressures and temperatures, and through the employment of additional heat recovery apparatus in the steam generating plant. Furthermore, one may see the introduction of new power generating equipment into central stations that at present is considered foreign to such uses. Also the possibilities of binary cycles are still to be fully explored and, as indicated by the excellent performance of some mercury-steam plants, these hold great promise of lower cost of power for base load plants where fuel costs are high.

The diesel engine is taking its place as a central station prime mover. In this country it has been used only in municipal stations and in some of the smaller privately owned plants. However, in South America and elsewhere stations of moderate size are employing diesel engines. Iddles proposes diesel engines for peak load capacity as these have the advantage of quick starting and small attendance costs. A recent European plant contains single units of 5000 kw each while much larger units were offered recently for a Canadian plant. The municipal plant at Vernon, Cal., contains five units of 7000 hp capacity each. A few years ago the writer had studies made of a diesel station of 50,000 kw capacity. This proved more economical than steam for the given location and load conditions. However in this case, cheap water power was purchased instead.

Further study should be given to plant auxiliaries. These have in the past been chosen largely on the basis of their reliability and operating characteristics. It would seem timely to study these auxiliaries from the point of view of power consumption under varying loads and of their influence on overall station heat rate. The auxiliary requirements may exert considerable influence on the latter. Present practice favors electrical drive for station auxiliaries with few steam-driven reserve units. Is there a place for steam-driven auxiliaries with the more efficient turbine drive now available? Can this auxiliary service be provided more cheaply by another power source? Internal-combustion engines have been developed to a high degree of reliability. Their construction and operation is known to every automobile user. It is possible that these engines may furnish cheaper

service for auxiliaries under variable-speed conditions than motor-driven units.

Auxiliary power may come from several sources. Among these, the house generator, driven by a separate house turbine, was a favorite some years ago. This was superseded by the house generator directly connected to the main turbine. The combination had the advantage of generating the auxiliary power at the same steam consumption as the main unit and also served as a stabilizer on the turbine speed in case the main unit dropped its load. In other cases auxiliary power is taken from the main generator through transformers placed between the generator terminals and the main switches. This also provides auxiliary power at a low steam consumption.

A few years ago the writer had a diesel-generator set installed for house service in a foreign plant. This has given satisfactory service at a low operating cost. This plant is several hundred miles distant from any other electrical service and hence had to start by itself. The diesel engine-generator being independent of other power sources, readily provided a-c power to the boiler and condenser auxiliaries and enabled the plant to be started with no difficulty. It can also be paralleled with the main units. Such engine-generator sets have some distinct advantages as house service units particularly for isolated plants.

Type of Building

A few years ago much discussion centered on the construction of out-of-doors power plants. Some enthusiasts estimated large savings in first cost from this type of plant. The writer recalls an experience many years ago when he had to reblade a turbine in a plant which had no heat except some salamanders and with outside temperatures ranging about 10 F below zero. Ever since that time he has been convinced that out-of-doors electric central stations have no permanent place in the colder sections of our country. In southern latitudes there is little need for protection of power plant machinery except to keep off sun and rain. In fact the writer when in Great Britain some years ago approved such a type of plant for the Far East.

The preceding comments would indicate that the out-of-doors plant is impractical from an operating and maintenance standpoint in our Northern states. As regards costs, little comparative data are available. There can be little saved on sub-structures; steel-work must be provided to carry the crane, and additional covers and operating run-ways must protect the machines from the elements. The costs of these offset much of the savings from omission of the usual building walls.

American designers have generally built high compact power houses. These, in some cases, are necessitated by the limited site available or by the high land values. British and Continental plants are characterized by a spread-out arrangement of equipment and low, less expensive buildings. Evidently considerable study can be devoted to the economies of the two types of construction. The urge to cut investment may lead to the adoption of plants of lesser height than heretofore.

Almost every old station has a solid wall separating the turbine and boiler rooms. This has been omitted with savings in cost in some recent stations. Modern boiler plants are relatively clean while turbines have few exposed parts that would be injured by dust. There is thus less justification than formerly for such a wall

and, as one of the economies of power house construction, it will probably be omitted in new stations.

The desire to make a plant attractive in appearance deserves encouragement. However, some of the embellishments of older plants are hardly warranted. Simple panels of different colored brick or tile can be made to produce pleasing effects at less expense than enameled materials. Plenty of natural lighting should be provided for all parts of the plant with good artificial illumination for night service.

There will be an increasing demand on the part of the public that the best of smoke-prevention and dust-catching equipment be embodied in the newer plants, particularly if these are located near residential or business districts. Dust-catching equipment, as at present developed, is large, bulky and heavy. If placed on top of the boiler room, it requires heavy and expensive steel work. In the spread-out construction this apparatus may be placed near ground level.

Recently published performance data indicate that cyclone separators remove from 60 to 72 per cent of the dust in flue gases though better performance is claimed for new types. Electrostatic separators remove from 75 to 95 per cent of the dust depending upon the size, number and rating of the units. Neither type removes sulphur or acid gases.

In Great Britain it is required that in new power plants near urban areas, not only must the dust be removed from the flue gases but the sulphur and other acid gases must also be washed out and neutralized. When one considers that a plant burning 1000 tons of coal a day with 2 per cent of sulphur will discharge into the atmosphere each 24 hr, 60 tons of sulphuric acid, 4 to 6 tons of nitric acid and often some hydrochloric acid, then one realizes the seriousness of pollution from these acids in residential areas. These gases attack limestone, mortars and cements, and lead to rapid deterioration of building materials. Many of our Middle Western coals carry from 2 to 5 per cent of sulphur. The destructive effect of the products of combustion of such coals must be tremendous and must result in unnecessarily high expense to residents of areas where such coals are burned.

Gas washing to remove sulphur compounds as developed by British engineers neutralizes the acids with lime water in a scrubber through which the gases pass. Settling basins provide for the removal of the products of these reactions in the latest process, thus providing a clear effluent which may be recirculated as lime water. The design involves large washing, reaction and settling chambers which add appreciably to the cost of the plant. Hence, we find new social demands for a clean atmosphere, offsetting the savings made in other directions in plant construction.

Some years ago an American engineer stated that he expected to see the day when the power plant would be required to return gases to the atmosphere as clean and acid-free as the air entering the furnaces. The British are already approaching that ideal condition.

Many plants have been designed for their ultimate capacity, often with provision for duplication of the original boiler and turbine units. When a station will be completed in a relatively few years, this construction may be warranted. In some cases the advantages of duplicate equipment, interchangeability, and few spare parts, may justify this practice. However, in general,

such plants fail to take advantage of progress in the art during the interval until final completion. This suggests the idea that new stations should be planned on a unit basis, each unit being complete in itself. In this way changes in load, or advances in the art of power plant construction, can be advantageously used in the design of the next unit. These units should be of the one boiler-one turbine type where possible, which arrangement has fully justified itself as a reliable combination in many existing power plants.

Modernization of Old Stations

The shortage of funds available for plant extensions will cause engineers to give serious study to the possibilities of modernizing old stations. The turbine-generators in these stations are seldom worn out in the sense that they are fit only for the scrap heap. In these turbines, blades and nozzles may be eroded, clearances may be large, condensers may require new tubes and generators may need some repairs. This maintenance can be provided at a moderate cost and the unit can be restored to good operating performance for the conditions for which it is designed. These older plants generally were built for steam pressure and temperature conditions now considered too low for good performance. The boilers are small and numerous. The furnaces are of too small a volume for high efficiency. Refractory walls only were provided. The stokers are of early types with high maintenance costs and a relatively poor economy. However, if proper depreciation funds have been provided, these old stations should have a low book value.

Studies may indicate the possibility of replacing these old boilers with large modern units inside the same building structure, and designed for higher steam pressure and temperature. Water-cooled furnaces with modern stokers or pulverized coal equipment and with air preheaters make high efficiency obtainable. Improved coal and ash handling arrangements cheapen boiler-room operation.

In the turbine room, a reducing unit can be installed to receive the steam from the boilers and to exhaust at the pressure and temperature conditions for which the older steam turbines were designed. The steam temperature from the new boilers should be chosen sufficiently high to provide a temperature at the exhaust of the new unit equal to the former operating superheat. This reducing turbine, depending upon new and old boiler pressures, may increase the capacity of the station from 10 to 20 per cent, and, at the same time, enable the station to show a thermal performance approaching that of modern plants. One must recognize that the older turbines which now act as low-pressure units, will not have as good efficiency as a new low-pressure section. Such a rebuilt plant could carry the regular loads of the system with satisfactory performance.

Utility operators frequently complain of the high charges of turbine builders for any reconstruction work on old units. This in many cases has prevented such rebuilding. A more liberal policy on the part of manufacturers would encourage much rehabilitation work to be undertaken.

Modernization in another manner is now being carried out at the Connor's Creek Station of the Detroit Edison Co. This station was originally built for three 20,000-kw turbines which operated at 225 lb per sq in. gage,

600 F and at a heat rate of 19,000 Btu per kw hr. The turbines are being converted to 30,000-kw units by additional new parts on the same foundations and using the same condensers. The boilers are being replaced with modern units in the same boiler space and using the same supporting steel as the old boilers. Modern under-feed stokers are also furnished. This reconstructed plant will operate at 600 lb per sq in. gage, 825 F and at a heat rate of 13,000 Btu per kw hr. This performance compares favorably with a new station while the cost of the change is said to be small compared to the cost of building a complete plant on a new site. Substructure, steelwork, coal bunkers, turbine foundations, condensers, intake and discharge tunnels, crane and much other equipment of the old station have not been replaced.

Many of the older stations are maintained only for peak load service or for standby to water power plants. In these cases, the expense of such reconstruction as outlined above, may not be warranted. Even in such a plant, increased capacity may sometimes be obtained at moderate expense. For instance, the addition of water-cooled walls to the furnaces together with a re-arrangement of the boiler tubes to form a slag screen will permit the operation of the furnace at greatly increased ratings and better efficiencies during peak loads or in emergencies. Frequently larger furnace volumes may be obtained at small cost by changes in the ashpit. Air pre-heaters can recover waste heat from flue gases and thereby increase boiler capacity and furnace efficiency. After boiler capacity is increased by these means, an additional turbine for peak load service can be added at a relatively low cost, thus providing increased station capacity at small expense. Some existing stations will warrant careful study to determine whether such improvements are the cheapest method of securing additional system capacity to be used on the peak rather than on the base of the load curve. If the life of the station is prolonged by these changes, depreciation charges will decrease, thus tending to lower the cost of power from the system.

Will modernization pay for itself? This is an individual problem for each plant and depends on the probable use factor and fuel cost in the reconstructed plant.

If the object of rehabilitation is to improve plant economy only, the savings to be effected in fuel costs during the correctly estimated operating life must pay an adequate return on the increased investment. This return must include interest, depreciation, taxes and insurance, plus an allowance for profit. The total varies with the expected additional life and use of the rehabilitated plant. It will seldom be less than 16 per cent and may be much higher. It is doubtful whether fuel savings alone will justify modernization of an old plant with no increase in capacity unless fuel prices rise much higher than at present, as compared to an investment in a new plant.

On the other hand, when fuel savings on the old plant are combined with a substantial increase in plant capacity, the problem is much altered. One can then allocate a proportion of the cost of rehabilitation to this added capacity and thus reduce the cost of securing better performance. One must determine whether this added capacity is secured cheaper than in any other way and also whether the fuel savings warrant the added expense

to secure them. This again is a problem local to each plant considered.

A few years ago the writer called attention to the possibilities of steam accumulators and turbines as a low cost equipment to carry peak loads. While these have been used abroad, none so far have been installed in central stations in this country due to the greater flexibility of American furnaces in carrying rapidly changing loads and to low banking costs.

The Designing Engineer

At the time these paragraphs are written the Wheeler-Rayburn Bill to dissolve holding companies is before Congress. Should this bill become law, certain difficulties may arise in the employment of the engineering forces of a holding company for modernization studies or for the design of a new plant.

While the various engineering subsidiaries of the holding companies and the independent engineering concerns render excellent and economical service, the writer has sensed a growing tendency on the part of the operating companies to do their designing and construction with their own engineering forces. This adds much to local pride. However, care must be observed that the local engineers have made the best analysis of the situation, are fully acquainted with developments elsewhere and are competent designers. The employment of experienced consulting engineers to review and advise on such proposed work, has, on many past occasions, proved highly remunerative and advantageous to the local companies.

If local talent is to be used, these engineers should be given an opportunity to travel about the country to observe and study the latest plants and to discuss their problems with operators of other utilities. Some companies in the past have been quite short-sighted in not providing their engineers with ample opportunities to look over and study the work of others.

F. H. Rosencrants a Vice President of Combustion Engineering Co.

At a recent meeting of the Board of Directors of the Combustion Engineering Company, Inc., F. H. Rosencrants was elected a Vice President, effective June 1, 1935. He will assume charge of the Proposition Engineering Department.

Mr. Rosencrants for a number of years was mechanical engineer with the Electric Bond and Share Company and later Chief Engineer of International Combustion, Ltd.

of England. In these positions he was responsible for the design of many of the outstanding plants in this country and the British Empire, and in 1928 received the award from the Institution of Electrical Engineers, Great Britain, for his paper on "Practice and Progress in the Combustion of Coal for Steam Generation," as the most valuable contribution on any subject presented that year.



What Every Boiler Operator Should Know About Superheaters

Circulation of steam in sufficient quantity through the superheater units is vital to the life and reliability of the equipment. Insurance of this during starting up and shutting down is discussed, as well as the effects of flame impingement, slagging and scaling due to moisture and carry over. The necessity for setting the safety valve on the superheater outlet several pounds lower than that on the boiler is explained and other factors within the control of the operator are reviewed.

MANY boiler operators appear to be of the opinion that the superheater can function successfully under the same conditions as the boiler heating surface. For this reason, superheaters frequently are abused and neglected, with the result that the life of the equipment is greatly reduced and the maintenance cost increased considerably. Such conditions can be avoided if a few points of difference as to boiler and superheater operation are borne in mind and reasonable care is exercised in the care of the superheater.

The boiler contains tubes of relatively large diameter, filled with water and absorbing heat from the gases of combustion. The superheater, on the other hand, consists of a large number of small diameter tubes filled with vapor and also absorbing heat from the hot gases. In the boiler tubes the water circulates naturally by its change in density as it absorbs heat. So long as there is water in the boiler drum, and there are no dead pockets, this circulation will continually remove the heat as it is conducted through the walls of the tubes. The natural circulation of the water and the absorption of heat by this water combine to protect the boiler heating surface. Should the boiler, for some unforeseen reason, be isolated suddenly from the main steam line, the boiler surface still is protected by the natural circulation of the water in the tubes. The safety valve, of course, will relieve the excess steam, but a continual supply of feedwater is injected, which maintains circulation as under normal operation on the line.

In the superheater a different condition exists. The circulation of steam through it depends entirely upon the pressure difference between the inlet and the outlet. This pressure drop is a direct function of the steam velocity which, in turn, depends upon the quantity flowing and the internal area of the tube. It can be said, therefore, that the proper combination of steam quantity and velocity provides the protection for the superheater. Since superheaters are installed between the boiler outlet and the steam main the steam flow through the units is assumed to be continuous. If the stop valve be closed, no steam will flow through the superheater units, and

By JOSEPH WAITKUS, Engineer
The Superheater Company, New York

both the steam velocity and the pressure drop become zero because the inlet and outlet ends of the superheater are at the same pressure. It is not difficult to visualize what will take place under such a condition. With no steam flowing to remove the heat as it is conducted from the outer to the inner surface of the tube the temperature approaches that of the gases flowing past the superheater. If this temperature is higher than the safe temperature for the tube material, failure may result from burning or oxidation of the material.

It may be concluded, therefore, that circulation of steam in sufficient quantity through the superheater units is of vital importance, particularly when it becomes necessary to start up or shut down the boiler. For a considerable period during both of these operations the boiler stop valve is closed and no steam passes through the superheater to the steam main, although hot gases are passing over the superheater surface. To meet this condition the superheater is provided with a suitable drain valve on both the saturated- and the superheated-steam headers. The purpose of the drain valve on the saturated-steam header is to remove any condensed steam in the header and thereby permit free movement of steam from the boiler to the superheater units. This valve is closed as soon as the condensate is drained away. The drain valve on the superheated header when open will permit circulation to take place through the superheater units which protects them while the boiler is gradually brought up to the operating pressure.

Too frequently operators give only a half turn to the drain valve, having in mind the saving of steam. While some circulation is set up thereby, it may not be enough to protect the superheater. The size of the valve is selected with the express purpose of passing sufficient steam to get the desired circulation, and boiler operators should take advantage of it. It is far better to lose a few dollars in steam than several hundred dollars in superheater tubing. The drain can be directed to a sewer or sump through piping of the same diameter as the valve. It should never be connected to a trap or any contrivance which might hinder the free flow of steam. When the boiler has reached the operating pressure and is on the line, then and only then should the drain valve be closed. When the boiler is being taken off the line the drain valve should be opened again as soon as the stop valve is closed, and remain open until the boiler is placed on the line again.

In some plants it is necessary to bring the boiler on the line far more rapidly than is normal practice. This requires a large release of heat in the furnace in order to

generate steam rapidly. To meet this condition plenty of steam circulation and velocity is necessary through the superheater units. Drain valves larger than those usually furnished will aid the situation. Under extreme conditions, as with a radiant-type superheater, it may be necessary to furnish steam from another boiler in sufficient quantity to keep the superheater cool until the boiler reaches the operating pressure and is placed on the line.

The boiler operator will find it very convenient to insert a thermometer in a thermometer well, located in the superheated-steam header, and, as the boiler is building up pressure, make periodic observations of the steam temperature. This will permit close control of the drain valve so as to keep the temperature down to a safe limit of about 800 F and at the same time drain only as much steam as is necessary to keep within this limit.

Operators sometimes raise the question as to why it is necessary to have the safety valve at the superheater outlet and, furthermore, why the safety valve should be set from 3 to 5 lb. below the setting of the boiler safety valve. These questions have a bearing on the circulation of the steam through the superheater units. When the boiler safety valve opens there is a rush of steam to the atmosphere and, since the pressure difference is greater through the safety valve than through the superheater units, practically the entire steam flow is directed through the safety valve. The superheater, therefore, is robbed of the steam needed to protect it. To remedy this condition, a safety valve is provided at the superheater outlet and is set from 3 to 5 lb. below the boiler safety-valve setting. The superheater safety valve, therefore, will blow before the boiler safety valve, which means that the steam, in passing from the boiler to the atmosphere, must pass through the superheater and thereby protect the units. Operators should be cautioned not to change the relative settings of the boiler and superheater safety valves, once they are set properly.

Now consider the gases flowing over the external surface of the superheater. The temperature of these gases frequently will determine, to a large extent, the

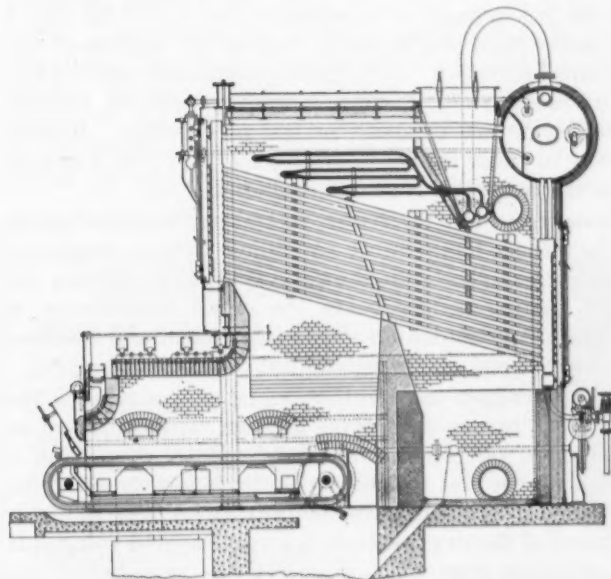


Fig. 1—Typical convection superheater in cross-drum boiler. The large amount of boiler heating surface ahead of the superheater protects the latter

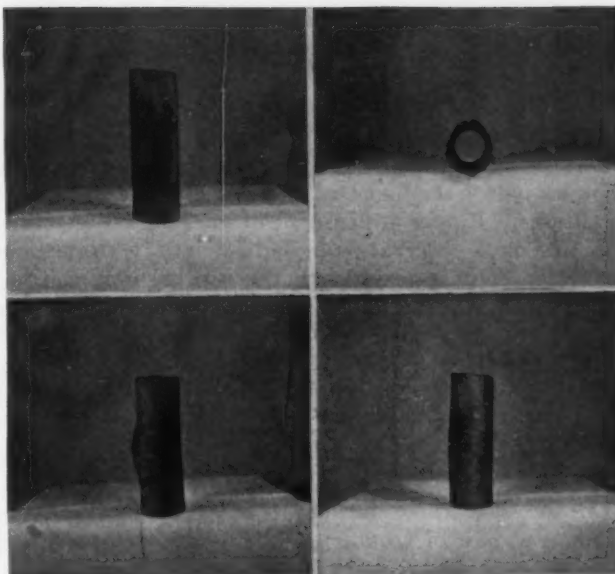


Fig. 2—A typical superheater tube failure caused by flame impingement

degree of care necessary in operating the superheater. For instance, a radiant superheater located directly in the furnace will require particularly close attention. The gas temperatures are sometimes in the neighborhood of 2500 F. Such temperatures would be most detrimental to any tube material used today in superheater manufacture, if steam flow ceased in the superheater units even for a short period. If, on the other hand, we consider the convection type of superheater, illustrated in Fig. 1, it will be noted that there is a large amount of boiler heating surface ahead of the superheater. This surface reduces the temperature of the gases considerably so that in passing over the superheater surface they are relatively low in temperature, compared to the radiant superheater. Cases have been reported, with superheaters of the type shown in Fig. 1, where there has been occasion to disconnect the superheater units from the header and, without removing the units, to continue operation of the boiler for quite a period. When these units were removed at some more convenient time they were found to be in good condition and ready for further operation. These, however, are exceptional cases and are cited simply as an illustration of the protection a superheater can get from the boiler heating surface ahead of it.

One of the greatest sources of trouble in superheater installations is flame impingement. If located in a region where flames can impinge on the tube surface, failure will occur sooner or later in spite of what may be considered as continuous and normal steam flow. It is not difficult to explain why this is so. The flame is hot enough to burn the tube surface and form a thin layer of oxide. The oxide then is worn away by the erosive action of the flame as it sweeps over the tube surface and uncovers the bare surface of the tube. The continual oxidation and erosion of the tube material soon wears the tube section down until it is too thin to stand the pressure and failure results. The time it takes to cause failure will depend upon conditions in the furnace combined with the quantity of steam flowing through the units and its velocity. The views in Fig. 2 illustrate a typical tube failure from flame impingement. Note

the thinned cross-section on the failed side, also the thin layer of oxide broken away in places on the tube surface. If flame impingement cannot be avoided the superheater surface must be covered with a protective material which can be renewed from time to time.

The point to bear in mind in connection with flame impingement is the fact that it is due entirely to furnace conditions. Proper adjustment of burners and combustion, and close observation of flame length, with particular notice of its proximity to the superheater, will aid materially in eliminating an important source of trouble. In giving furnace operation data for the design of a superheater, too frequently information regarding flame conditions is omitted, with the result that trouble arises because provisions were not made to protect the superheater properly, nor to install it in a more advantageous position.

On the subject of furnace conditions another very common source of trouble, is the so-called "secondary combustion." Superheater design is based on the assumption that combustion of the fuel is completed in the furnace and that only the products of combustion pass over the surface of the superheater. This applies to the convection superheater. The radiant type, of course, depends largely upon the heat radiated from the flame. A properly designed furnace is provided with sufficient volume in which the fuel is burned completely, so that

only the resulting gases of combustion pass over the heat-absorbing surfaces. If the furnace is deficient in volume, this deficiency will be made up in the gas passes where the fuel will continue to burn, if sufficient air is present to support combustion. Assuming the furnace has sufficient volume, if the proper amount of air is not provided for complete combustion in the furnace, the unburned gases will pass through the boiler and burn at points where air leakage through the setting will furnish sufficient air for further combustion. Applying these two conditions to a superheater located as illustrated in Fig. 3, there will exist, in the first place, a condition almost analogous to flame impingement and, in the second place, the superheater is being robbed of the gases it normally would get under proper furnace operation. In the first case, surface oxidation and erosion may be expected, with the additional evil of a very high degree of superheat due to temperatures on the external surface being higher than anticipated; and in the second case, the superheat is likely to be low because of insufficient gas flow and low gas temperatures.

Slagging is well known among boiler operators but its effect on general boiler performance frequently is overlooked. Slagging is the result of furnace operation which creates a furnace temperature so high that the ash becomes molten or plastic. The particles of ash in this state are carried up into the boiler tubes where they solidify and cling to the relatively cool tube surface. The accumulation progresses until a fairly thick layer is deposited on the leading surface of the tubes. Slag has a very low coefficient of heat transfer, hence surfaces covered with it are very materially reduced in their efficiency as heat absorbers.

The effect of slagging on superheaters will depend largely upon the type of boiler used and the location of the superheater. For example, in Fig. 1 the superheater is well protected by the boiler heating surface. There is little danger of slag accumulating on the superheater surface. Slag accumulations on the boiler heating surface, however, will cut down their heat pick-up enough to cause the superheater to be subjected to gas temperatures higher than anticipated, causing high superheat. On the other hand, a superheater located as in Fig. 3 will suffer from slag deposits, causing low superheat, unless care is exercised. Superheaters frequently are located, as indicated in Fig. 4, where again a reasonable amount of boiler surface is ahead of the superheater. Results similar to those from the arrangement in Fig. 1 can be expected from this type of installation.

Boiler operators, therefore, should pay strict attention to the furnace temperature and adjust furnace conditions so as to keep the temperature of the gases entering the boiler heating surface below the fusion temperature of the ash. Any amount of slag is a detriment and a serious menace to good operating results.

Few operators realize that moisture content of the steam or "carry-over" plays a most significant part in superheater operation. The fundamental purpose of a superheater is first to remove whatever moisture may be contained in the saturated steam, then to raise the temperature of the dry steam to a predetermined value. If the moisture content is excessive the superheater actually is functioning as a boiler and the heat which otherwise would be used to raise the temperature of the steam is being utilized to evaporate water. This in itself is a

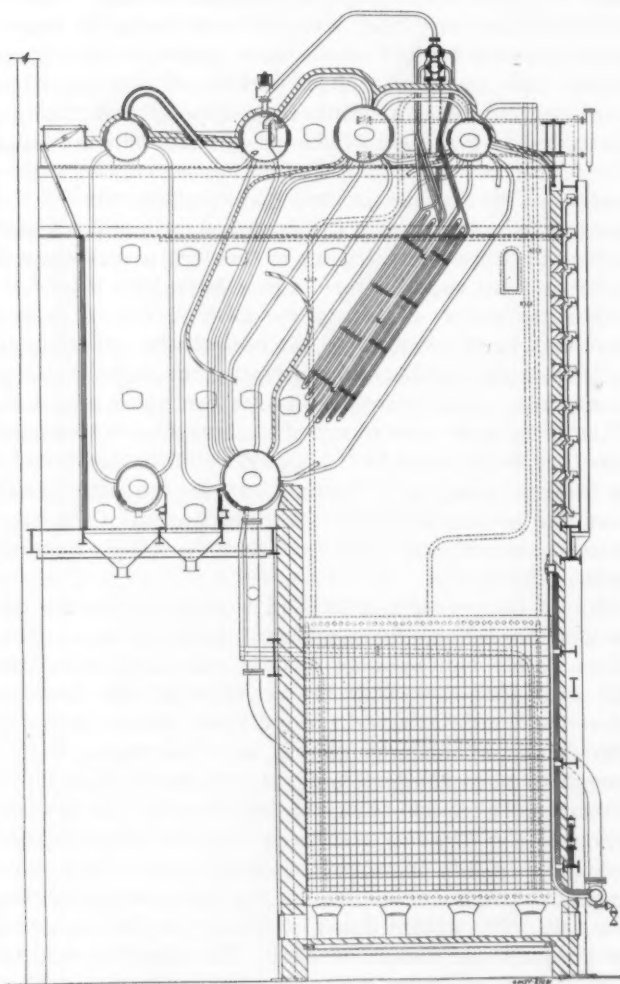


Fig. 3—An intertube superheater in semi-vertical boiler may suffer from slag deposits or excessive gas temperatures, unless care is exercised in operation. Location of burners not shown

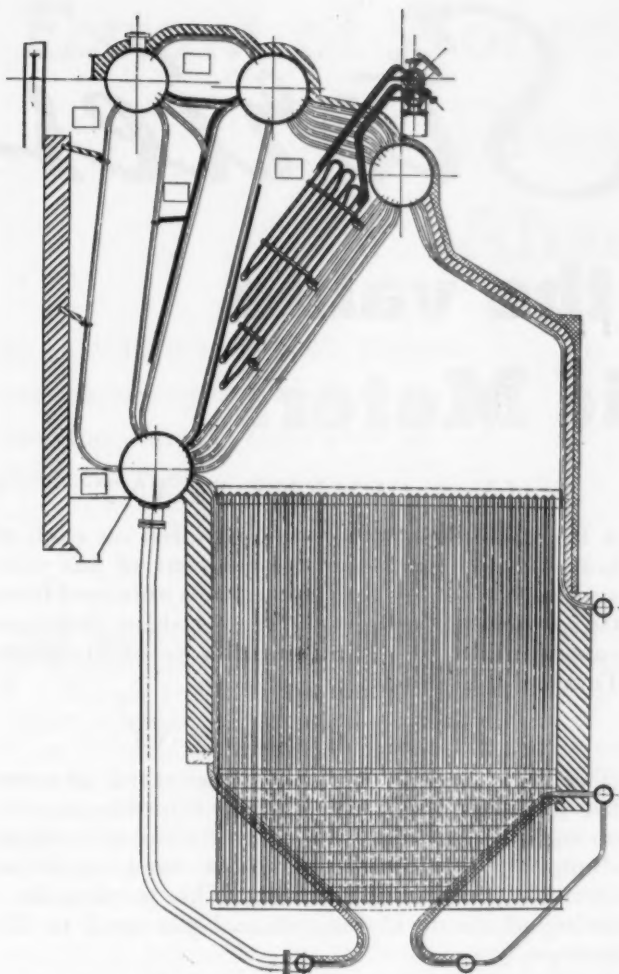


Fig. 4—Superheater entirely behind tube bank of semi-vertical boiler. The boiler tubes protect the superheater. Location of burners not shown

serious condition, but the more important problem is the formation of deposits on the inner surface of the tubes due to this excessive moisture. Boiler feedwater, whether treated or not, contains certain proportions of chemicals which form a deposit as the water is evaporated. These same chemicals are contained in the moisture carried over into the superheater with the saturated steam. As the moisture is evaporated under the influence of the rather high temperatures characteristic of superheating surface a deposit forms on the inner surface of the superheater unit and thus begins the forma-

tion of scale. In time the scale formation will build up to a considerable thickness and restrict the flow of steam. Since the area of the tube cross-section is reduced, the steam velocity is increased because it varies inversely as the area of the free cross-section of the tube. Contrary to general expectations the increase in velocity does not always clear the tube of scale because the deposit is sometimes too firm to be readily removed by steam flow. Furthermore, there is no increase in heat absorption as the result of the higher steam velocity, because the scale is a very poor conductor of heat. If heat cannot penetrate easily to the steam the cooling effect is reduced or entirely eliminated. As a result, the tube will be burned at the point where the scale formation exists.

Since superheaters cannot be inspected conveniently for scale formation, close attention should be given to the condition of the saturated steam. A sampling tube properly located in the connecting pipe between the boiler outlet and the superheater inlet will permit the use of a steam calorimeter to determine the percentage of moisture present in the steam. It has been established that not more than one per cent of moisture is a safe limit. If this figure is exceeded immediate steps should be taken to ascertain the cause.

In conclusion, it is evident that the boiler operator has within his control factors which are of great importance to successful superheater operation and performance. As soon as he learns to appreciate the value of each of these factors, much better operation can be expected and less trouble will be experienced throughout the life of the superheater. A systematic and periodic inspection of operating routine and conditions will pay in reduced maintenance cost and greater reliability.

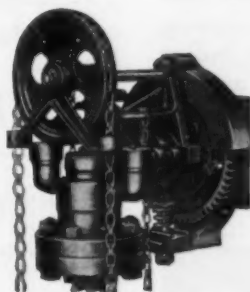
Edward Smiley has been appointed Sales Manager of Cyrus Wm. Rice & Co., Inc., water chemists and engineers, with headquarters in Pittsburgh. The company also announces that A. J. Forschner, formerly President of the Atlas Conveyor Company, has joined its organization in its Philadelphia office.

Wesley R. Moore has been made manager in charge of the joint office of the Brown Instrument Company and Minneapolis-Honeywell Regulator Company which was recently established in the Marietta Street Building, Atlanta, Ga. Associated with him will be Leon L. Kuempel, Charles A. Kitzinger and J. A. Crawley.

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IN A PACKING PLANT

A small western meat packing plant operated two boilers which consumed on an average of one car of coal in seven days. Republic instruments were installed on the two boilers and the coal consumption was reduced to one car in nine days. A saving of 11 cars of coal per year—a return which paid for the instruments in 8 month's time.

IN A CREAMERY

Three Republic meters were installed to measure the total steam consumed by the plant, the high pressure and low pressure steam to the butter-milk units. The saving in amount of steam consumed resulting from the intelligent use of these meters amounted to \$1,500.00 the first year. Cost of meters—\$975.00

IN A LAUNDRY

The chief engineer of a Chicago laundry writes: "The Republic steam meter, CO₂ meter and draft gage which we installed on our 200 H.P. boiler some two years ago have enabled us to reduce our fuel bill approximately 10%. This is a saving which, in my opinion, few laundries can afford to overlook."

IN A BREWERY

A brewery was about to replace an old 150 H.P., hand fired boiler with a new stoker fired boiler of the same size. Before making the change, they installed a Republic meter on the old boiler and discovered that at peak load they were operating at over 200% of rating. Obviously a larger boiler was needed to handle the load efficiently and to take care of any future expansion. Here the installation of a Republic meter saved the costly mistake of installing too small a boiler.

REPUBLIC FLOW METERS CO.

2230 DIVERSEY PARKWAY, CHICAGO, ILL.

IN A CEMENT PLANT

A Republic flow meter was installed on each of four kilns to measure the amount of gas consumed. Guided by the information obtained from these meters they were able to reduce their gas consumption by 10%. Cost of meters—\$1,200.00. Total saving—\$36,000.00 per year.

IN AN INK PLANT

Here three boilers were being operated to carry the plant load. After installing Republic meters on each of the boilers they found that with slight changes in firing methods the load could be carried with only two boilers. This resulted in a saving of about 15 tons of coal per week or 780 tons per year.

SELLING STEAM

A western warehouse was selling steam to one of its tenants at a flat rate of \$75.00 per month. The tenant thought that they were being over-charged so a Republic meter was installed to measure the amount of steam actually used—the tenant to be billed accordingly. Now the tenant is paying around \$250.00 per month. The meter cost \$325.00 and saved the warehouse company \$175.00 per month, or \$2,100.00 per year.



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Extent of Corrosion of Iron in the Presence of and in the Absence of Oxygen

By SALVATORE ALFANO, Chemist
Deepwater Station
Houston Lighting and Power Co.,
Houston, Texas

AS long as the principal material of engineering construction continues to be iron in its simpler forms, problems of corrosion and corrosion prevention will arise. In a modern station in which all the steam is condensed and returned to the boiler as pure condensate the question is an important one. Plant operators have minimized corrosion troubles by careful control of the oxygen content of the boiler water and close adherence to the proper pH of the feed.

In general, corrosion troubles in boiler plants have been the result of corrosion being concentrated in small localized spots resulting in pits about the size of a penny or smaller. It is with these concentrated localized corrosion spots or pits that the plant operator is mainly concerned. If the total amount of iron corroded from the pits were uniformly dissolved from all the wetted surface, the extent of corrosion would not ordinarily be noticeable.

Many otherwise well-informed plant operators are not aware that a general corrosion or gradual distributed wasting away of metal often goes on in a boiler plant even under water conditions which give protection against the localized pitting or ordinary form of corrosion. This may also occur in feed lines, pumps and related equipment. Some engineers and chemists have observed the difficulty in distinguishing between "corrosion" and "erosion," and prefer to use the term "corrosion-erosion," particularly as applying to cases of rapid wasting-away of metal.

Such gradual general wearing-away of metal has become noticeable in connection with high-output, base-load, high-pressure boilers, and in some cases, where the boilers operate continuously for several months with practically no blowing, small deposits of iron compounds are accumulated without evidence of localized corrosion. A discussion of the probable sources and extent of such accumulations may contribute to better understanding of corrosion problems generally.

Corrosion may be defined as any dissolution of, or change of form of, a refined metal to a more stable condition. The most common occurrence of corrosion is that of iron to its oxide.

It is hardly conceivable that the iron deposits found in a boiler are due alone to the metal removed by the

A review of the fundamental chemical principles underlying corrosion. Due to the inherent solution pressure of iron it will dissolve until it reaches its saturation value, but with oxygen present it is precipitated and the corrosive action goes on. Methods of measurement are discussed, as is the effect of pH values and the problem is presented from the standpoint of the power plant operator.

formation of pits. In fact, such deposits are more often noted where no localized corrosion is observed.

Where the volumetric capacity of a boiler is large, the presence of some iron oxide deposits may not appear objectionable and may not be noted. However, if the steam output is large and the volumetric capacity of the boiler relatively small (which is usually the case with 1400-lb steam boilers), the accumulation of iron deposits becomes important. Especially is this true in high-pressure equipment required for the best efficiency of the plant. Although the iron deposits may be considered non-scale forming, they are dense and adhere strongly to the boiler tube surfaces. They have a metallic luster and may deceive the casual observer as to the condition of the tube surfaces.

In the absence of any noticeable corrosion the iron deposits might be explained by any or all of the following reasons:

1. Action of steam on hot iron above metal temperatures of 950 F is a possibility, especially with steam temperatures of 800 to 1000 F.
2. Erosive or physical action of water, wet steam or a combination of water and steam on metal surfaces such as centrifugal pump impellers and other parts, trap discharge lines, particularly where the hot drips flash at the trap discharge, etc.
3. General corrosion of boiler and feedwater equipment both in the presence and absence of oxygen. This may be termed electrolytic corrosion.

Most operators are familiar with the wearing or wasting away of the metal in zones of restricted circulation. They are also acquainted with the wear of pump runners, impellers and diffusers. Where corrosion is highly localized and pitting ensues, electrolytic corrosion is easily recognized. Relatively few operating men appreciate the extent of corrosion where it is uniformly

distributed and its effects are not readily discernible. However, for stations in which the steam is all condensed and returned to the boilers and where the makeup is evaporated, there is a method by which the extent of such electrolytic corrosion can be measured.

A statement of the fundamental chemical principles involved will be of interest and assistance in understanding the phenomenon of corrosion and the methods of measurement suggested herein. If zinc is immersed in a solution containing dissolved iron, the zinc will go into solution and an equivalent amount of iron will deposit on the zinc. Likewise, if a strip of iron is immersed in a solution containing dissolved copper, iron will dissolve and an equivalent amount of copper will deposit on the iron strip. In a similar manner, as the zinc ions displaced the iron ions in solution and iron ions displaced copper ions in solution, iron displaces hydrogen from solution (as hydrogen ion) because hydrogen behaves in all respects like a metal.

Iron does not dissolve readily in concentrated sulphuric acid, because the latter has few or no hydrogen ions; but if the acid is diluted with water the iron will dissolve readily in it, because in diluted form hydrogen ions are present. The tendency of the iron to go in solution is greatest when there are the greatest number of hydrogen ions in solution. However, if the dilution of the sulphuric acid is carried too far the concentration of hydrogen ions is not increased, but actually decreased, and the attack on the iron will be greatly diminished. Further, by diminishing the concentration of the hydrogen ions in a dilute sulphuric acid solution by neutralization with an alkali the dissolution of iron will be reduced. Continuing the addition of alkali until the neutral point is passed and the alkaline side is reached, the amount of iron that can go in solution will be reduced in proportion to the amount of alkali added. But, whether the solution is acid or alkaline, a certain amount of iron will go into solution until a definite relation between the dissolved iron and the hydrogen ion in solution is reached. Then the iron will cease to dissolve.

When a strip of iron is immersed in a copper solution some will dissolve and an equivalent amount of copper is deposited on the iron until the solution contains both copper ions and iron ions. The solution will never be void of copper ions. There will always remain a certain amount of copper in solution even though the iron has the capacity to displace the copper. So it is in the case of iron with hydrogen ions. Not all the hydrogen is displaced by the iron before iron ceases to dissolve. There will be some hydrogen ions left.

Water, although neutral, contains hydrogen ions (H^+). It also has hydroxyl ions (OH^-). The number of hydrogen ions (H^+) depends on the number of hydroxyl ions (OH^-). In water the product of (H^+) \times (OH^-) is a constant for constant temperature. This constant, which is the ionization constant of water, is at ordinary room temperature 1×10^{-14} . Expressed mathematically: $(H^+) \times (OH^-) = 1.0 \times 10^{-14}$, where the ions in bracket are expressed in mols per liter. In an aqueous solution, regardless of the concentration of (H^+), the (OH^-) are fixed in accordance with this equation. In water the concentration of (H^+) is equal to the (OH^-); that is, (H^+) = 10^{-7} mols per liter. If the hydrogen ion concentration is desired in terms of pH the negative of the exponent of 10 is taken. Thus, the

negative of the exponent of 10 is in this case $-(-7)$ or $+7$. In neutral water the pH value is 7; yet there are enough hydrogen ions to be displaced by iron.

The extent of dissolution of the iron depends on the hydrogen ion content of a liquid (acidity) and on the number of ferrous ions in solution. If the hydrogen ions (H^+) in a liquid are those due to water or to an alkali, the product of the dissolution of the iron (corrosion) is ferrous hydroxide, $Fe(OH)_2$. If a strip of iron is immersed in neutral water, the iron will continue to dissolve until the solution is saturated with ferrous hydroxide, $Fe(OH)_2$. (J. W. Shipley & I. R. McHaffie, *Ind. & Eng. Chem.*, 17, 381 (1925).)

In order to make more clear how iron goes in solution as ferrous ion (Fe^{++}), the reader is referred to the concept of solution pressure first introduced by Nernst (*Zeit. Phys. Chem.*, 4 (1889)). This concept is that all solids have a tendency to go into solution just as do table salt or sugar. If sugar be placed in a beaker and water added, its tendency to go into solution is greatest at the start. As the solution approaches saturation, the tendency of the sugar to dissolve becomes less. If the solution is supersaturated the tendency of the sugar to dissolve is negative and sugar will deposit out of solution. The tendency to go into solution is its solution pressure; the tendency to go out of solution is its osmotic pressure. At the beginning the osmotic pressure is zero but the solution pressure is very great. When saturation is reached the solution pressure is balanced by the osmotic pressure. If supersaturation is attained osmotic pressure exceeds solution pressure and sugar tends to go out of solution.

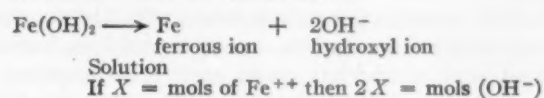
Thus, when iron is in contact with water its solution pressure will drive into solution ferrous ions (Fe^{++}) until the osmotic pressure balances the solution pressure. When this condition is reached dissolution or corrosion will cease. At this stage there is sufficient ferrous hydroxide to produce a pH of 9.6.

Normally in boiler feedwater, especially in the case of condensate at the condenser, the concentration of dissolved iron is zero at the start of its cycle. The osmotic pressure is then zero and the solution pressure of the iron is unopposed. Hence, iron tends to go into solution. This is corrosion and will occur irrespective of whether there is any dissolved oxygen present. It can be limited, but not completely stopped, by increasing the pH (alkalinity) value of the feedwater. Corrosion will cease when the saturation point of ferrous hydroxide ($Fe(OH)_2$) is reached, the saturation of which is dependent on the pH value of the water. Therefore, an amount of iron equal to that which is in solution in a saturated solution of ferrous hydroxide $Fe(OH)_2$ cannot be prevented from dissolving into the water if the time of contact is sufficiently long.

Since corrosion of iron depends both on pH value of the water and on the dissolved iron, it is interesting to note in what way these factors are interdependent. Consider first what is the pH value of a saturated solution of ferrous hydroxide $Fe(OH)_2$. It was said that water ionizes to hydrogen ions (H^+) and hydroxyl ions (OH^-). Furthermore, in an aqueous solution the product of these ions, for constant temperature, is a constant. Likewise, when a difficultly soluble salt, such as ferrous hydroxide, $Fe(OH)_2$, is dissolved in water, the $Fe(OH)_2$ in solution ionizes into ferrous ions, Fe^{++} , and hydroxyl

ions (OH^-). Just as in the case of water where the product of the (H^+) and (OH^-) is a constant, so it is with $\text{Fe}(\text{OH})_2$. The product of (Fe^{++}) and 2 (OH^-) for $\text{Fe}(\text{OH})_2$ is called the solubility product. In chemistry the symbols in brackets with an electric charge signify ionic concentrations, which are expressed in mols per liter. One mol per liter is equivalent to the molecular weight in grams of the substance present in a liter of solution. Thus, the molecular weight of the hydroxyl ion is 17 and 17 grams of hydroxyl ion in one liter of solution corresponds to one mol per liter.

According to E. Muller (*Zeit. Electroch.*, 14.77 (1908)) the solubility product of $\text{Fe}(\text{OH})_2$ at 18 C is 1.64×10^{-14} . Expressed mathematically: $(\text{Fe}^{++}) \times (\text{OH}^-)^2 = 1.64 \times 10^{-14}$. In accordance with the following equation it is seen that one mole of $\text{Fe}(\text{OH})_2$ ionizes to one mol of Fe^{++} and 2 mols (OH^-):



The solubility product for ferrous hydroxide becomes:

$$\begin{aligned} (X)(2X)^2 &= 1.64 \times 10^{-14} \\ 4X^3 &= 1.64 \times 10^{-14} \\ \text{Fe}^{++} = X &= 1.588 \times 10^{-5} \\ (\text{OH}) = 2X &= 3.18 \times 10^{-5} \end{aligned}$$

Remembering that in water $(\text{H}^+) \times (\text{OH}^-) = 10^{-14}$, the (H^+) in $\text{Fe}(\text{OH})_2$ can be calculated by substituting the value of $2X$ in the ionization constant for water; thus $(\text{H}^+) \times (3.18 \times 10^{-5}) = 10^{-14}$ from which $(\text{H}^+) = \frac{10^{-14}}{3.18 \times 10^{-5}} = 0.315 \times 10^{-9} = 10^{-9.5}$. And so the pH being the negative of the exponent of 10 is $-(-9.5)$, or $+9.5$, which agrees closely with the 9.6 value of Shipley and McHaffie (*Ibid.*). The concentration of the constituent ions in a saturated ferrous hydroxide solution are:

	Mols/liter	ppm
(Fe^{++})	1.59×10^{-5}	0.888
(OH^-)	3.18×10^{-5} ($10^{-4.5}$)	0.540
$\text{Fe}(\text{OH})_2$	1.59×10^{-5}	1.428
(H^+)	$1 \times 10^{-9.5}$	

Whitman (*Jour. Am. Chem. Soc.*, 47, 70 (1925)) found that ferrous hydroxide is only 30 per cent ionized at its saturation value. The other 70 per cent remains unionized and does not affect pH or conductivity measurements. Hence, the total iron in solution is greater than the concentration of the ions measured by the pH value.

The total iron, ionized and un-ionized is $\frac{1.428}{3}$ or 4.76 ppm.

The foregoing are the equilibrium concentrations when iron ceases to go into solution and the original water was neutral.

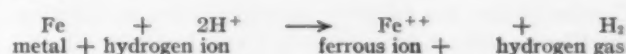
Since the pH value of a saturated solution of $\text{Fe}(\text{OH})_2$ is 9.5, does it necessarily follow that if the pH value of water is purposely raised to 9.5 by conditioning the water with alkali (NaOH), no iron will dissolve? The answer is "No." Iron can still go into solution but in reduced proportions to the alkalinity in the water initially.

Whitman (*Ibid.*) found that there is some iron possible of solution regardless of the initial pH of the water. This solubility, however, drops with increasing initial pH. At pH of 11 solubility is nearly zero. This sug-

gests that the initial rate of corrosion (dissolution of iron) is not affected by the presence of an alkali until the pH is above 11. According to the data (Whitman, W. G.; Russel, R. P.; Davis, G. H. B.; *Jour. Am. Chem. Soc.*, 47, 70 (1925)) only when the initial pH of the water is greater than 9.5 does the rate of corrosion (in the absence of oxygen) lessen. There is still a positive value for dissolution of the iron until the initial pH of the water is above 11.5.

Thus, by conditioning water with NaOH to bring the pH value to 9.5 the amount of iron to go into solution is reduced but not entirely prevented. Hence, while it can be said iron in neutral water will corrode until the pH value of the solution is 9.5, it is not conversely true that raising the pH value of the water to 9.5 beforehand will entirely eliminate corrosion. It should be remembered that the antecedent of the higher pH of the solution, which was formerly neutral, was the dissolution of the iron to ferrous hydroxide. Thus, in addition to alkalinity, the ferrous iron, Fe^{++} , must be present in solution to prevent further dissolution where the pH of the water is initially less than 11.5.

Summing up, one stage of corrosion is due, according to Nernst, to the inherent solution pressure of iron; thus,



Corrosion will not be stopped completely by merely increasing the pH value of the feedwater. It will cease only when a certain amount of iron has gone into solution. Corrosion can be completely stopped by introducing in the feedwater a neutral or alkaline solution of ferrous ions, Fe^{++} , by external means instead of allowing the solution to become saturated with respect to ferrous ions, Fe^{++} , at the expense of the feed lines, equipment and boiler metal.

This type of corrosion, in the absence of dissolved oxygen, continues as long as the iron surface is clean and free from scale. This continuous corrosion is of sufficient magnitude that it can be measured under suitable conditions by the conductivity method, which permits of quantitative analysis where amounts involved are of small magnitude. (Hecht & McKinney, "Electrical Conductance Measurements of Water and Steam," A.S.M.E., June 1930). The conductivity method of determining the extent of electrolytic corrosion is limited, however, to plants in which all the steam is condensed and returned to the boiler as pure condensate and where the makeup is evaporated.

It is of interest to note the extent of this corrosion in modern high-pressure stations. Consider the flow cycle of Fig. 1. In order to determine the extent of electrolytic corrosion by the conductivity method, it is necessary to know the conductance of the steam and water at the points indicated on the diagram.

With a Leeds & Northrup conductivity cell (cell constant 0.1) the specific resistance of steam out of the saturated header of the high-pressure boiler was found to be 2,100,000 ohms. The specific resistance of the condensate (average of 3 condensers) was found to be 1,980,000 ohms. The resistance of the makeup, which is evaporated, averaged 1,100,000 specific ohms. The boiler feedwater as it enters the high-pressure boilers had a specific resistance of 1,730,000 ohms.

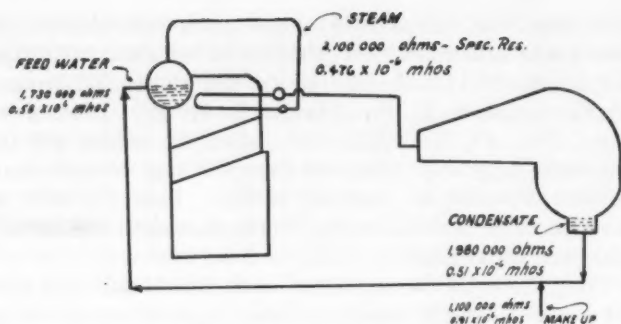


Fig. 1—Steam and water flow diagram

Since the conductivity of the steam is the least of all conductivity measured it may be assumed that the steam condensed at the extraction heaters is of the same purity as the condensate at the condensers. If the conductivity of the steam at the boilers had been greater than that at the condenser, then it would be necessary to determine the amount of steam bled and its conductivity at each extraction heater in order to ascertain what part of the increase in the conductivity of the feedwater is due to solids carried over into the steam and redissolved at the extraction heaters.

Conductivities are additive in water when no dilution takes place. Hence, the resultant conductivity of the feedwater is the sum of the conductance of the individual ions in the water. If there is no dilution then the conductivity, being proportional to the dissolved solids in the feedwater, should remain constant since the ionic concentrations are constant.

If the conductivity increases, then additional ions must enter the water. In this analysis, the increase in the conductance of the feedwater is assumed to be due to electrolytic solution of iron since no other sources of ions are assumed in contact with the feedwater.

If: S denotes the conductance of the feedwater
 S_c the conductance of condensate
 S_m the conductance of makeup—2 per cent of the total
 S_{cm} the conductance of the condensate plus makeup
 $S_{Fe^{++}}$ = the conductance ferrous ion

It follows that:

$$\begin{aligned} S &= S_{cm} + S_{Fe^{++}} \text{ where } S_{cm} = 0.98 S_c + 0.02 S_m \\ S_c &= 0.51 \times 10^{-6} \text{ mhos} \\ S_m &= 0.91 \times 10^{-6} \text{ mhos} \\ S_{cm} &= 0.98 (0.51) \times 10^{-6} + 0.02 \times 0.91 \times 10^{-6} \\ &= 0.50 \times 10^{-6} + 0.018 \times 10^{-6} \\ S_{cm} &= 0.52 \times 10^{-6} \text{ mhos} \\ S &= (0.52) 10^{-6} + S_{Fe^{++}} = 0.58 (10^{-6}) \end{aligned}$$

Whence:

$$S_{Fe^{++}} = (0.58 - 0.52) 10^{-6} = (0.06) 10^{-6} \text{ mhos.}$$

Also:

If: S be the specific conductance
 C be the concentration of the ions in equivalents per liter
 L be the equivalent conductance of the solution.

By definition:

$$L = \frac{1000S}{C} \text{ and } C = \frac{1000S}{L}$$

Equivalent conductance of iron as the ferrous hydroxide is

$$\frac{1}{2} L_{Fe^{++}} + L_{OH^-} = \frac{L_{Fe(OH)_2}}{2} = 45.3 + 174 = 219.3$$

Substituting the values of that part of the feedwater conductance due to electrolytic solution of iron in the above equation, we have:

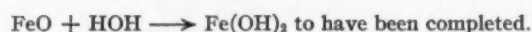
$$C = \frac{1000(0.06)10^{-6}}{219.3}$$

$$C = 0.274 \times 10^{-6} \text{ grams equivalent of } Fe(OH)_2 \text{ per liter.}$$

Since the equivalent gram molecular weight of $Fe(OH)_2$ is half its molecular weight, the concentration in ppm = $0.274 \times \frac{89.86}{2} \times 10^{-3} = 0.0123 \text{ ppm.}$

The conductivities at the various points mentioned were measured at the same temperature after several weeks without condenser leakage or appreciable priming of the evaporators. The specific conductivity of the evaporator makeup approximated 1,000,000 reciprocal ohms.

The data presented were not taken with the thoroughness required for a scientific research problem, but were obtained with somewhat more care than required for ordinary routine data. The assumption that the 0.0123 ppm of the $Fe(OH)_2$ is due to iron from the feedwater equipment may be erroneous. It would be possible that action of hot steam on hot metal could have generated a little FeO which could have been carried over with the steam and which would not be detected in the steam sample nor the condensate as there might have been insufficient length of time for the ferrous oxide to dissolve. But, as carried by the feedwater to the boilers, there should have been sufficient time for the reaction.



Thus, with feedwater carrying 0.0123 ppm of $Fe(OH)_2$ there accumulates 0.0123×12 or 0.1476 lb of $Fe(OH)_2$ per day when evaporating 12,000,000 lb of steam per day from the high-pressure boilers. In a year a total of 53 lb, or 26.5 lb per boiler, could be accumulated.

From a theoretical viewpoint, iron may be expected to continue to go into solution as long as the feedwater is not saturated with ferrous ion. Since in a condensing steam-generating station, water makes many cycles and at the start of the cycle (condenser hotwell) is very pure and void of any traces of iron, the solution pressure results in some iron continuously dissolving, notwithstanding the absence of oxygen. This type of corrosion is difficult to check. Whitman (*Ibid.*) has shown that in the absence of oxygen the initial rate of dissolution of iron is independent of initial pH of the water as long as the pH is below 11.5. At an initial pH 9.5 Whitman still shows about 75 per cent as much iron will dissolve as when the initial pH was 7.0 (neutrality). With an initial pH of 10, in the absence of oxygen, the amount of iron dissolving is 50 per cent of what it could be when starting with neutral water.

Thus, iron will continue to corrode as long as the water in contact with it is void of ferrous ions (Fe^{++}). There is a belief that this type of corrosion can be minimized by raising the pH of the feedwater, say to 9.5, and this is sometimes attempted by blowing back from the boilers some alkaline water into the feed system. In order to render a water alkaline to the extent that its pH is raised to 9.5 from the neutral condition pH 7.0, about 1.5 ppm of NaOH must be maintained. To raise the pH to 10.0 would require approximately three times as much blowback. With the low concentrations usu-

ally maintained in high rating base-load high-pressure boilers, these values would require about 2 to 6 per cent blowback which might appreciably disturb the efficiency of the heat cycle. This is on the assumption that the actual concentration of NaOH is on the order of 60 to 80 ppm.

Further, the efficacy of sodium hydroxide from the boilers in retarding corrosion is partly vitiated since it is accompanied by three to four times its quantity of other salts such as Na_2SO_4 and NaCl . Hence, NaOH of itself could only reduce the corrosion possibilities of the feed about 25 per cent and any good that it might do to reduce corrosion is counteracted by the adverse influence of salts, as the sulphates and chlorides.

Where makeup is supplied through evaporator plants and raw water is rich in carbonates, it is difficult to remove completely all traces of CO_2 which will have the adverse effect of lowering the pH of the boiler feed. Fortunately, this type of corrosion in the absence of oxygen is of small magnitude at ordinary water flows and the operator does not have to be concerned about the practical effects except at points of highly turbulent conditions where the corrosion products are removed as fast as they are formed and fresh surfaces presented for continued attack. The type of attack often called erosion may be a case of accelerated corrosion; or, at least a combination of erosion and corrosion.

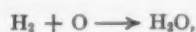
Inasmuch as raising the initial pH of the feed, even as high as 9.5 or 10.0, has only a limited effect as regards protection against corrosion, the main benefit of such control lies in the assuredness of preventing the water from ever falling on the acid side under which conditions the corrosion is tremendously accelerated.

The corrosion of iron, in the absence of oxygen, has a definite limit and will soon stop when a definite amount of iron is dissolved, depending upon the initial pH of the water. But, in the presence of oxygen there is no limit to the extent of the corrosion of iron. It takes place *after* the corrosion in absence of oxygen has commenced. The first stage of corrosion of iron in pure water takes place in the *absence* of oxygen as already noted and stops when enough iron has dissolved to raise the pH of the water to 9.5.

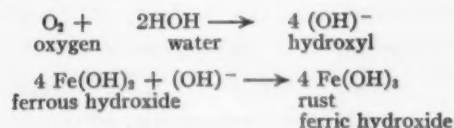


If conditions are not disturbed, no more iron dissolves. But, if either or both constituents to the right (Fe^{++} or H_2) are removed, corrosion will continue.

The second stage of corrosion is in the *presence* of oxygen. The function of oxygen in promoting corrosion is to remove H_2 gas or ferrous ion in solution so that the first stage of corrosion will never come to a definite end. Oxygen can accelerate corrosion by removing hydrogen gas, thus:

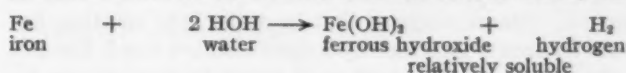


or, it can oxidize the more soluble iron to the very insoluble condition as follows:

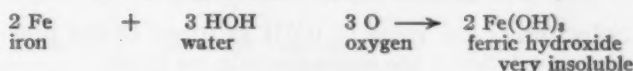


A substance will react in the direction to form its most stable form.

Ferric hydroxide (ordinary rust) is extremely insoluble, while ferrous hydroxide is relatively soluble. In the presence of water but in the absence of oxygen, iron seeks its most stable condition which is the ferrous state, thus:



In the presence of oxygen, the pure metal seeks a still more stable condition, namely, as the ferric hydroxide:



In the presence of water and oxygen, the pure iron seeks its most stable form or rust.

A mere statement of the foregoing facts may not impress the non-chemist reader of the really destructive influence of oxygen in destroying iron in the presence of water; so let us translate the above idea into the language that is

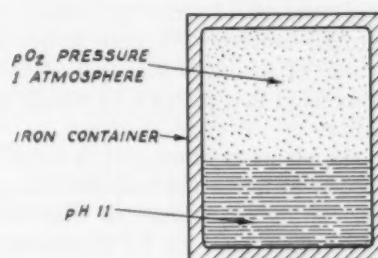
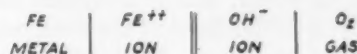


Fig. 2—Illustrating cell effect between iron bomb and oxygen



more easily understood by the plant operator. Most plant operators are acquainted with the term, pH, and concentrations in parts per million. They know that pH is a measure of the alkalinity (or acidity) of water—the higher the pH, the more caustic the water and the lower the pH, the more the water is toward the acid side. Furthermore, operators know that it is desirable to have water in contact with iron on the alkaline side. The tendency of the iron to dissolve (corrode) is increased many times by water which is acid. It can be shown that oxygen actually makes the water touching the iron acid.

The two forms of the corrosion product of iron are:

1. $\text{Fe}(\text{OH})_2 \longrightarrow \text{Fe}^{++} + 2(\text{OH})^-$ oxygen absent.
ferrous hydroxide ferrous ion hydroxyl ion
2. $\text{Fe}(\text{OH})_3 \longrightarrow \text{Fe}^{+++} + 3(\text{OH})^-$ oxygen present.
ferric hydroxide ferric ion hydroxyl

The pH values of water can be calculated when iron seeks its most stable form, both in the absence of oxygen and in the presence of oxygen. The stable condition for the corrosion product of iron in the absence of oxygen has already been calculated to be that condition where the pH is 9.5 and solubility of ferrous hydroxide to be 4.76 ppm. Making similar calculations for the ferric hydroxide:

$$(\text{Fe}^{+++})(\text{OH}^-)^3 = 1.1 \times 10^{-36} \text{ (Muller-Ibid.)}$$

If:

$$\begin{array}{l} X = \text{number Fe}^{+++} \text{ in solution} \\ 3X = \text{number of } (\text{OH}^-) \end{array}$$

and the equation becomes:

$$\begin{aligned}(x)(3X)^3 &= 1.1 \times 10^{-36} \\ 27X^4 &= 1.1 \times 10^{-36} \\ X &= 4.49 \times 10^{-10} \\ 3X &= 13.47 \times 10^{-10}\end{aligned}$$

Now $3X$ represents the number of hydroxyl ions in solution. Remembering that in water the relation between hydroxyl ions and hydrogen ions are fixed, the pH of the solution in contact with ferric hydroxide can be calculated from the ionization constant of water.

$$\text{In water } (H) \times (OH)^- = 10^{-14}$$

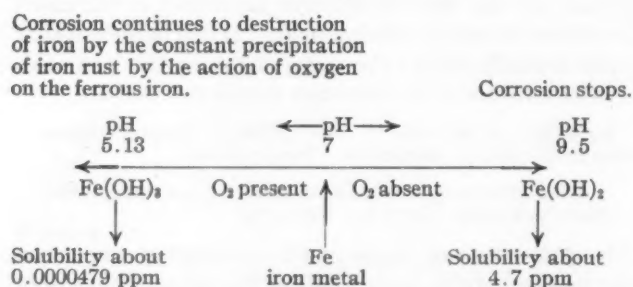
Substituting the value of $(OH)^-$ as found in the preceding calculation in the above formula, we have:

$$\begin{aligned}(H^+) \times (13.47 \times 10^{-10}) &= 10^{-14} \\ (H^+) &= \frac{10^{-14}}{13.47 \times 10^{-10}} = 0.0743 \times 10^{-4} = 10^{-5.13}\end{aligned}$$

The pH being the logarithm of $\frac{1}{H}$ becomes 5.13.

Thus, the pH value of water in which iron and oxygen are present in a saturated solution of ferric hydroxide is 5.13. Therefore, a saturated solution of ferrous hydroxide, $Fe(OH)_2$, the pH value of which is 9.5, will in the presence of oxygen be converted to a pH of 5.13 which is on the acid side of neutrality.

It will be seen that in the presence of oxygen, a condition will obtain which tends to make the solution more acid (lower pH). This causes more iron to dissolve since there are more hydrogen ions to be displaced. Hence, not only does oxygen disturb the first stage of corrosion by converting the iron to the least soluble state and the hydrogen to water, but it increases the acidity of the water in the neighborhood of the iron, and accentuates the first stage of corrosion. Thus, two forces normally antagonistic toward each other are in play. On the one hand, iron dissolves in water to reach the stable condition where its pH will increase to 9.5. Corrosion would stop here. On the other hand, oxygen destroys the higher pH and seeks to establish a lower pH and renders the water acid, during which time nearly all the soluble iron in the ferrous state is precipitated as rust. Presented graphically the conditions are as shown as follows:



Ferric iron (rust) is 100,000 times less soluble than ferrous iron. The vicious corrosion cycle can be better visualized now. Due to the inherent solution pressure of iron which cannot be stopped, iron will dissolve in order to reach its saturation value. With oxygen present this iron is completely precipitated to leave almost none in solution. In doing this oxygen lowers the pH from 9.5 to 5.13. This results in a water in contact with the iron which is acidic and which is void of ferrous ions. Such a condition accentuates the corrosion of iron. As long as there is available a supply of oxygen the corrosion cycle will never cease. The rate of turnover, that is

from metal to ferrous to ferric, depends on the rate at which oxygen can diffuse to the metal and to the initial corrosion products.

It can now be shown how the first stage of corrosion can be accelerated by the presence of dissolved oxygen in water. It was shown that at equilibrium when iron ceases to corrode the following conditions were set up:

$$Fe(OH)_2 \text{ system: pH} = 9.5; Fe(OH)_2 \text{ 4.76 ppm}$$

But with oxygen present the $Fe(OH)_2$ system tries to reach a new equilibrium:

$$Fe(OH)_2 \text{ system: pH} = 5.13; Fe^{+++} 0.0000251 \text{ ppm}$$

But the ferric hydroxide system is so far removed from the ferrous system that iron will go into solution to satisfy the ferrous hydroxide system which is the antecedent of the ferric hydroxide system. These two systems can never be in equilibrium when iron is in contact with water in which there is unlimited oxygen present.

This presents the conclusion that the arresting of oxygen corrosion is possible only by complete removal of oxygen or possibly by creating conditions whereby the ferrous system is in equilibrium with the ferric system. Is this possible? Can the two systems be in equilibrium under definite concentration of dissolved oxygen and definite pH? As will be proved subsequently the condition is created when the dissolved oxygen concentration is infinitesimally small.

Assume the condition of a boiler where the pH value of the water is 11. How much oxygen can be tolerated without causing corrosion?

Consider the destruction of iron by oxygen to be electro-chemical in nature. To evaluate the oxygen concentration which will not cause corrosion, the oxygen concentration at equilibrium must be determined, when iron corrodes in presence of excess oxygen, which oxygen will not be augmented as the reaction proceeds to completion. Consider the scheme shown in Fig. 2. An iron bomb is filled with pure oxygen, at a pressure of one atmosphere, and with NaOH solution the pH value of which is 11. A cell is thus created; one electrode is the iron of bomb, the other the invisible oxygen. The iron electrode has a potential different from the oxygen electrode and is of opposite sign. The difference of potential between the iron and oxygen electrode will cause the dissolution of iron to the ferric state and oxygen to the hydroxyl state. Dissolution of iron and disappearance of oxygen in the compartment will continue until the potential difference between the iron-ferrous potential and the oxygen-hydroxyl potential is zero. When this is reached the oxygen will have been nearly all used up. All, however, cannot completely disappear. There will be a certain amount of oxygen in the compartment when the reaction has ceased, and of course a proportionate amount of oxygen dissolved.

Now when the pH of the water is 11 the $pOH = 3$. The concentration of ferrous ion that can exist under this alkalinity is fixed in accordance with the solubility product principle. For ferrous hydroxide the solubility product is

$$(Fe^{++}) \times (OH^-)^2 = 1.64 \times 10^{-14}$$

$$\text{since } (OH^-) = 10^{-3}; Fe^{++} \text{ becomes } \frac{1.64 \times 10^{-14}}{(10^{-3})^2}$$

$$= 1.64 \times 10^{-8} \text{ mols per liter, or } 0.000000915 \text{ ppm of iron.}$$

$$\text{The ferric ion that can exist is } \frac{1.1 \times 10^{-36}}{(10^{-3})^3} = 1.1 \times 10^{-27} \text{ mols per liter or } 6.15 \times 10^{-26} \text{ ppm.}$$

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Selection and Design of Equipment for Burning Illinois Coal*

By HENRY KREISINGER

Combustion Engineering Company, Inc.

ILLINOIS coal is hard. It is generally harder than the impurities that it contains. For this reason lump coal usually has a lower ash content than slack. The coal is of laminar structure consisting of thin layers of shiny black material alternating with a dull brownish substance. It breaks along the layers and at right angles to the layers. This tendency of fracture gives the lumps somewhat cubical shapes. Owing to its hardness the coal stands handling without excessive breakage.

Compared to eastern coals Illinois coal runs high in sulphur and ash, and the latter fuses at relatively low temperatures. The coal is free burning, that is, it does not soften and fuse into large masses of semi-coke, but the individual pieces keep their shape and remain separate until completely burned. When heated a large part of the combustible is driven off as gas, and if improperly burned dense black smoke is produced. In storage the coal is inclined to spontaneous combustion; hence, does not store well.

Of the different types of mechanical stokers now on the market the traveling grate (or chain grate) stoker is the best suited for burning Illinois coal. The natural hardness of the coal keeps it comparatively free from excessive fines, which makes the resistance of the fuel bed to the flow of air nearly uniform over the entire grate. This nearly uniform resistance results in a uniform flow of air over the entire grate and freedom from burned-out holes in the fuel bed. It also prevents to a large extent short and long fires existing at the same time at the rear of the stoker.

Owing to the free burning property, the individual pieces of coal burn separately without fusing together into large masses of semi-coke, the air is nearly uniformly distributed over the grate and the coal burns evenly over the full width of the grate. This is the principal requisite of a good traveling grate stoker coal. The opposite of free burning coal is caking coal. Such coals when burned on a traveling grate become pasty and fuse into large slabs of semi-coke. These slabs crack in a few places and the air supplied through the grate flows only through the cracks, with the result that these slabs of semi-coke do not burn completely by the time they reach the end of the grate, and a large percentage of the combustible matter is wasted with the ashes.

The comparatively high ash content of the Illinois coal is another requisite of a good traveling grate stoker fuel. The burned-out ash on the rear part of the stoker forms a substantial covering over the grate and protects

The physical properties of Illinois coal are reviewed and the types of fuel burning equipment and furnace arrangements best suited to meeting these conditions are discussed. Typical furnace designs for both traveling grate stokers and pulverized coal are included.

it against the reflected heat from the arch. Because of the fact that during the passage of the coal through the furnace the fuel bed is not agitated, the ash is not lifted into the hot fire and fused into hard clinker. Any clinker that is formed is soft and spongy and is not detrimental to the operation of the stoker.

When coking coals are burned on a grate the fuel bed must be agitated to break up the large masses of semi-coke. Such agitation lifts the ash into the burning fuel and when the ash has a low melting temperature it is fused into sticky clinkers. Eastern coals are caking coals and they are generally burned on multiple-retort underfeed stokers which are designed for agitation of the fuel bed to break up the large masses of semi-coke. However, they have ash with comparatively high melting temperature.

The gases rising from the fuel bed on the front part of the chain grate stoker contain a high percentage of combustible which must be mixed with air and burned before it leaves the furnace, otherwise smoke is produced. Hence, the furnace above the grate must be designed so as to facilitate this mixing and promote combustion. The rear arch furnace design shown in Fig. 1 gives very good results in this respect. It directs the air flowing into the furnace around the rear end and through the rear part of the stoker into the stream of combustible gas rising from the front part of the stoker. The two streams are mixed while passing through the comparatively narrow throat between the nose of the arch and the front wall, and the combustible burns in the combustion space between the throat and the boiler.

Fig. 2 shows what is likely to happen in a badly designed furnace represented in outline in the lower part of the sketch. The upper part contains two charts; that on the left gives the composition of gases rising from the fuel bed, while that on the right gives the gas composition at the section where the furnace gases enter the boiler. The composition of the gases rising from the fuel bed were obtained by collecting samples 2 in. above the top of the fuel bed at various points indicated by the small circles. These samples were analyzed and the results plotted on the chart directly above. The composition of furnace gases entering the boiler was obtained by collecting gas samples above the first row of boiler tubes at the points

* From a paper presented at the Third Annual Mineral Industries Conference at the University of Illinois, May 17 and 18, 1935.

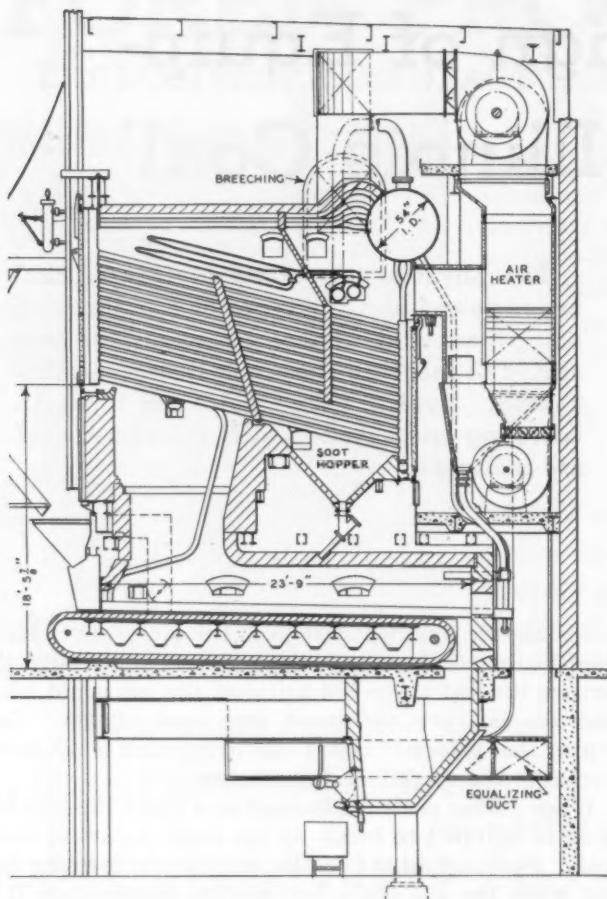


Fig. 1—Typical traveling grate stoker installation with rear arch furnace design well suited to burning Illinois coal

indicated by the small circles. The bottom chart gives the pressures in the various air compartments under the grate. The gases at points 1 to 5, inclusive, contain large percentages of combustible and very little or no oxygen to burn this combustible. The gases at points 6 to 7a, inclusive, contain no combustible but very large percentages of free oxygen. Because the furnace was poorly designed the combustible gas was not mixed with the free oxygen, and the two streams flowed separately into the boiler. As indicated by the analysis of gases in the first pass the two points on the left of the second chart show very high carbon dioxide content and practically no free oxygen, whereas the two points near the rear wall show very low percentages of carbon dioxide and very high percentages of oxygen. The furnace smoked badly even at moderate ratings and the smoke inspector threatened to shut down the plant.

Fig. 3 shows the same furnace as that in Fig. 2, modified to eliminate the smoke. The modification consists of a provisional rear arch placed close over the grate. This arch directed the air passing around the end and through the rear part of the grate into the stream of combustible gas. The two streams were fairly well mixed by passing between the throat formed by the rear and the front arch. Most of the combustible gas burned before it entered the boiler. The composition of the gases in the first pass was nearly uniform across the whole pass, as is indicated by the two curves in the chart above the rear part of the furnace.

With a uniform bed of burning fuel no free oxygen passes through the fuel bed, and all the oxygen com-

bins with carbon either as carbon monoxide or carbon dioxide. Free oxygen must be admitted over the fuel bed and mixed with the gases in order that the combustible may be burned. With a traveling grate stoker such free oxygen enters the furnace around the end and through the rear part of the stoker. The furnace must be designed to produce mixing of the two streams of gases, and combustible space must be provided so that combustion may take place. It may be suggested that the combustible rising from the fuel bed is mostly volatile matter and that if the fuel did not contain this volatile matter the oxygen might possibly work its way through the fuel bed uncombined.

Fig. 4 shows that the gases rising from a bed of burning fuel contain a large percentage of combustible even though the fuel is coke and the bed only 6 in. thick. This represents the results of a study of combustion in the fuel bed of burning coke, as made at the U. S. Bureau of Mines nearly twenty years ago. The figure is a combination of five charts giving the composition of gases at five different rates of combustion. The top chart represents the rate of combustion of 20 lb of coke per square foot of grate per hour, the next chart below represents rate of combustion of 38 lb, the third chart 51 lb, the fourth chart 71 lb and the bottom chart 106 lb. On the left the ordinates give the percentages of each constituent of the gases, and those on the right give the temperature in the fuel bed. The abscissa represent the height above the grate in inches. The fuel bed was 6 in. thick and samples of gas were collected 1 1/2 in., 3 in. and 4 1/2 in. above the grate in the fuel bed, also at the surface of the fuel bed and 1 1/2 in. from the top. It is interesting to note that in every case there was no free oxygen at the top of the fuel bed; in fact most of the free oxygen disappeared 4 1/2 in. above the grate. The rate of combustion was obtained by forcing more air through the fuel

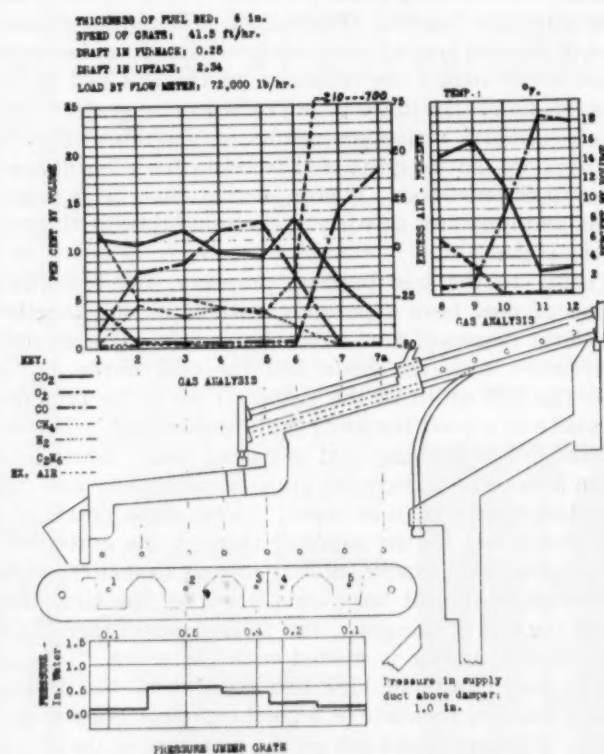


Fig. 2—Composition of gases rising from the fuel bed of a traveling grate stoker and the results of the lack of mixing in a poorly designed furnace

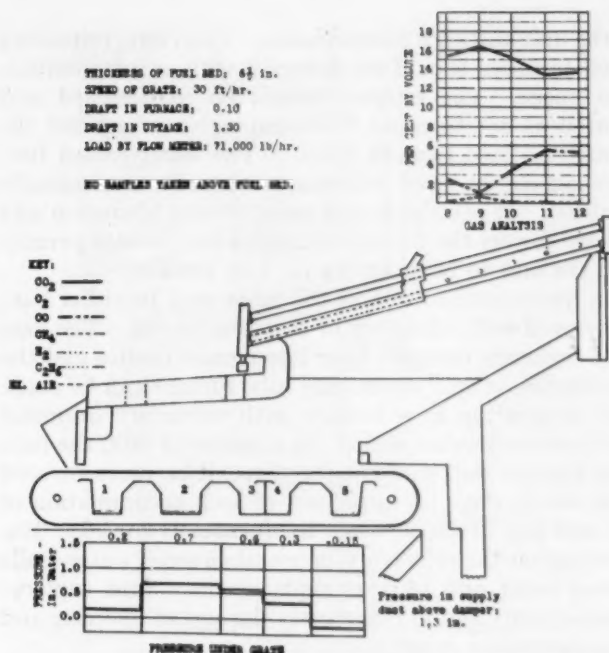


Fig. 3—Provisional rear arch to produce mixing of air with combustible gases in a poorly designed furnace

bed. For example, in test 42 when burning 106 lb per sq ft per hr the weight of air supplied through the fuel bed was $5\frac{1}{4}$ times that supplied in test 48 having a rate of combustion of only 20 lb. This means that the oxygen will combine with the carbon as fast as it is supplied, and the composition of gases in the fuel bed and above it remains practically the same for all rates of air supply and rates of combustion. It will be noted that the combustible at the top of the fuel bed is about 16 per cent with all rates of combustion.

Fig. 5 shows a traveling grate stoker installation under a bent-tube boiler. This furnace is characterized by a rear arch, narrow throat and large combustion space above the throat for burning combustible gases. The furnace was designed for burning high volatile Kansas coal. Both arches of the furnace are water cooled, as are also the side walls above the throat. Besides this water cooling there is a water-cooled tube on each side of the furnace just above the grate. These tubes in the side walls prevent the ash from sticking and dragging the fuel bed along the walls. For Illinois coal the water-cooled furnace is very desirable and greatly reduces maintenance. The installations shown in Figs. 1 and 5 are well adapted for burning Illinois coal without smoke.

The traveling grate type of stoker is used for units varying in size corresponding to evaporations of 10,000 to 100,000 lb of steam per hour, with this kind of coal. For smaller boilers the type E stoker or the so-called spreading stoker are used with satisfactory results. For units larger than 100,000 lb of steam per hour the traveling type of stoker becomes too large and costly. Large stokers must be built very heavy to prevent distortion by the driving mechanism or deformation by heat and the stalling of the stoker. The difficulty of keeping a uniform length of fire increases with the width of the stoker; the wider the stoker the greater the chance of having long and short fires at the same time.

This does not mean that all installations with steaming capacities of 10,000 to 100,000 lb per hr are to employ traveling grate stokers and that above 100,000 lb pulver-

ized coal is to be used exclusively. There are many pulverized coal installations with a steam output in the above range. Such installations are put in because of special local advantages, personal likings or some peculiar load conditions favoring pulverized coal. It means, however, that in this range the stoker partisan has a real argument in his favor.

With large steam generating units it is difficult to get in enough grate area to give the required high steam output. The capacity of the steam generating unit increases as the cube of the linear dimension, whereas the grate area increases only as the square. The pulverized coal furnace, however, increases also as the cube of the linear dimensions.

Illinois coal is well suited to firing in pulverized form. The high volatile content makes it ignite quickly and a stable fire is maintained even at very low rates of working. Its natural hardness is somewhat against it because this reduces the output of the pulverizer, and increases the power consumption per ton of coal pulverized. Maintenance is also somewhat higher than with the soft eastern coals. However, with proper selection of the mills, this disadvantage due to its hardness is negligible. The high percentage of ash and its low fusion temperature are also somewhat detrimental. The higher ash content increases the cost of pulverization and is apt to cause greater dust nuisance resulting from the large quantity of ash being discharged with the gases from the stack. The low fusion temperature is an advantage with slag-tap furnaces. It is also a disadvantage because

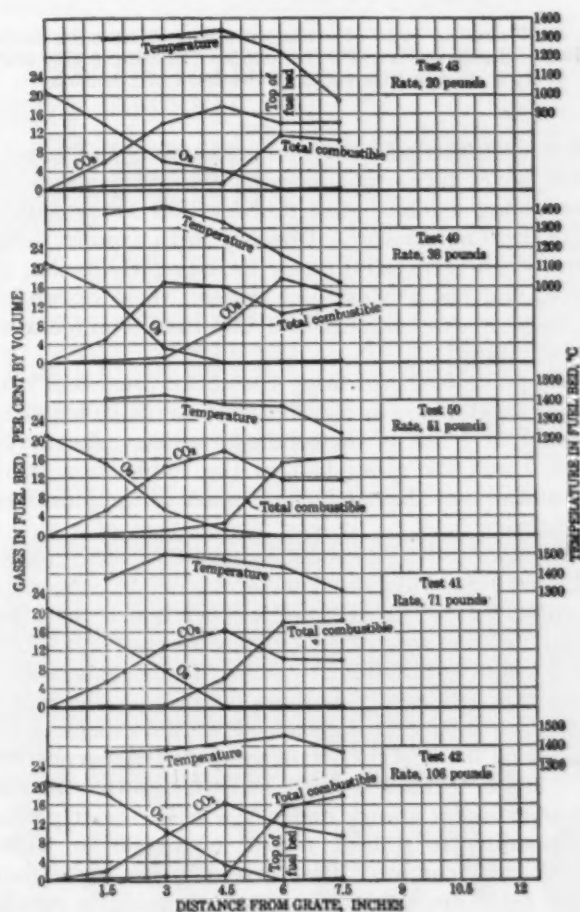


Fig. 4—Composition of gases in a bed of burning coke: fuel bed, 6 in. thick and rates of combustion 20, 38, 51, 71 and 106 lb of coke per hour per square foot of grate

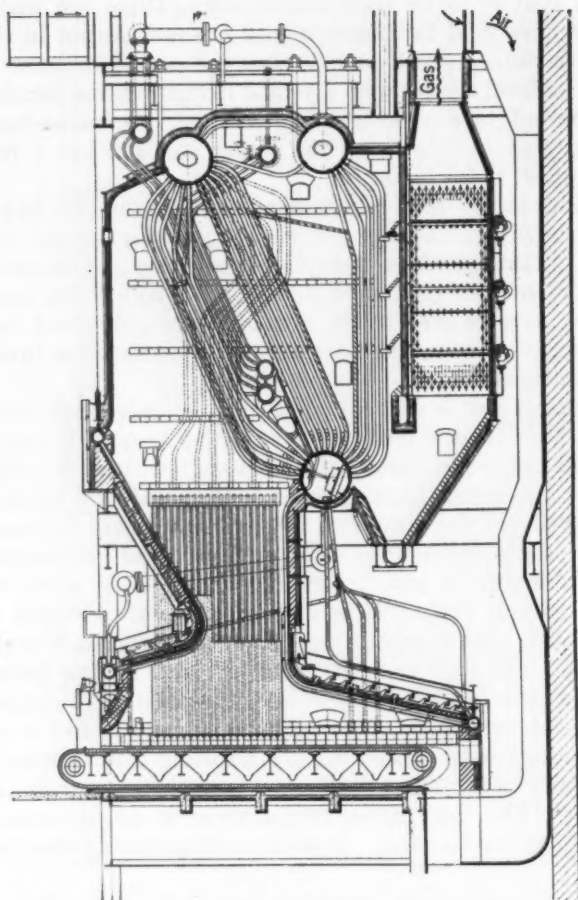


Fig. 5—Traveling type of stoker under a bent-tube boiler. Arches and side walls are water cooled. There is also water cooling on the side walls at the level of the stoker

molten ash is carried into the boiler and may be deposited on the boiler tubes thus clogging the gas passages and necessitating a forced shut down. This is particularly true of slag-tap furnaces. However, with a proper design of the steam generating unit, including the boiler, the furnace and the ash disposal system, these drawbacks due to high ash contents and low fusion temperature can be nullified.

With pulverized coal firing the entire process of combustion takes place in the furnace. With stoker firing approximately half of the combustion takes place in the fuel bed and the other half in the combustion space. This means that the combustion space of the pulverized coal furnace must be at least double that of a stoker-fired furnace. The usual rate of combustion of Illinois coal when burned in pulverized form is one to two pounds per cubic foot of furnace volume per hour. In a few installations the rate of combustion reaches $2\frac{1}{2}$ lb and in still fewer installations to 3 lb. These high rates of combustion are usually of short duration. The rate of combustion is largely determined by the design of the furnace and the selection of material used in its construction. If the furnace is lined with refractories the rate of combustion is always under $1\frac{1}{2}$ lb per cu ft per hr, corresponding to a heat release of 14,000 to 16,000 Btu per cu ft per hr. If in these furnaces higher heat release rates are used the refractory lining is rapidly wasted away by the molten particles of ash that are sprayed on it by the pulverized coal flame. Such wasting away of refractory lining results in frequent shutdown

of the unit and high maintenance. Therefore, refractory lined furnaces should be designed with ample combustion space. The burners should be so designed and located as not to cause flame impingement against the refractory-lined furnace walls. The water-cooled furnace should be used wherever it can be economically justified. It permits higher rates of heat liberation and greatly lowers the furnace maintenance, besides permitting the unit to be in service for long periods.

In water-cooled furnaces the tubes may be either bare or covered with refractory or cast-iron blocks. The bare tube walls are cheaper, have lower maintenance and the combustion of coal in the bare tube furnace can be made just as good as in a furnace with refractory or metal block covered water walls. As a matter of fact, the bare tube furnace wall does not stay bare, it becomes covered with ash or slag. A large part of such accumulation of ash and slag drops off when the furnace is cooled. The covering on the refractory or metal covered water walls wastes away and requires replacement. Such replacement is costly and in many cases the cost of covering and its maintenance is not justified.

Fig. 6 shows a steam generating unit with water-cooled furnace walls on three sides. The fourth wall is of refractory because it contains the burners as it is easier to fit the burners into a refractory wall than into a water-cooled wall. The flames move away from the burner wall and therefore do not impinge on it. There are six of these burners placed in two rows and three in each row. The long flame travel from the burners to the tubes of the boiler results in complete combustion and greatly reduces the chances of ash being deposited on the boiler tubes, and clogging the gas passages. The ash on its long path through the water-cooled furnace is

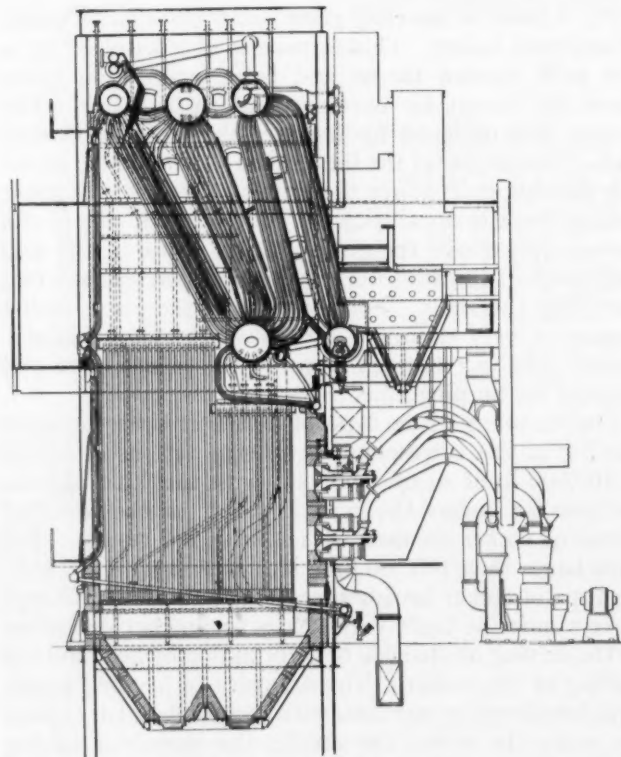


Fig. 6—Pulverized coal fired water-cooled furnace. Water cooling is on three sides; the burner wall is made of refractory because of simplified mechanical construction. Burners are located under the lower drum of the boiler giving the furnace a long flame travel

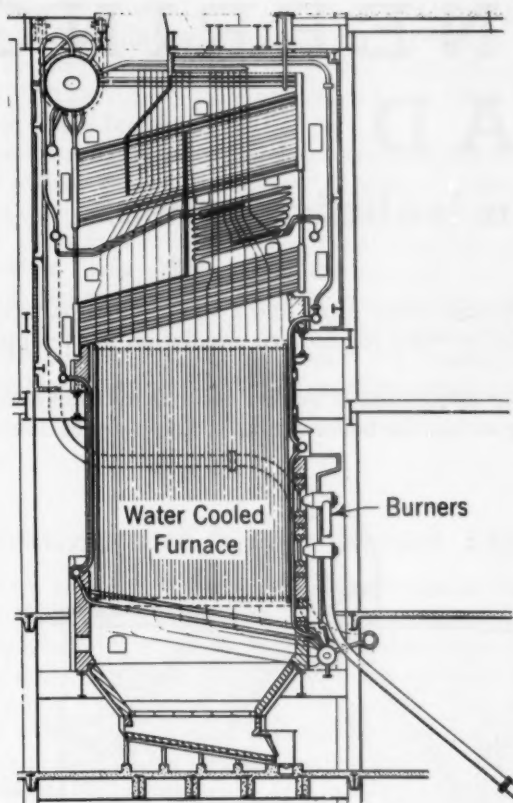


Fig. 7—Completely water-cooled furnace for burning pulverized coal or fuel oil. Ash from coal is removed in granular form through sluice

cooled below its sticky temperature and does not adhere to the boiler tubes. Any ash that may be deposited among the tubes of the first bank is easily dislodged with a hand lance inserted through peepholes in the top part of the rear wall. The ash dropping to the bottom of the furnace passes through a water-cooled screen over the bottom of the furnace, is cooled down below its sticky temperature, and removed from the ash hopper in a granular form. This unit has a maximum capacity of 300,000 lb of steam per hour and is installed in an industrial plant. It is well suited to Illinois coal.

Fig. 7 is another steam generating unit well adapted for Illinois coal. The furnace is completely water cooled including the burner wall. The boiler is of the sectional-header type with an interdeck superheater. The unit is fired with eight horizontal burners placed in two rows one above the other. Coal is supplied from a pulverized coal storage bin located in an adjacent building. The burners are of such design that either pulverized coal or fuel oil can be burned. The change over from one fuel to the other can be made one burner at a time without changes in the load on the boiler. The unit was designed for generating 550,000 lb of steam per hour at 750 lb pressure, and is installed in a central station.

Illinois coal is hard and has a high ash content. These properties make it somewhat hard to pulverize. The capacity of all types of pulverizing mills will be lower and the maintenance higher with Illinois coal than with most of the eastern coals. The maintenance is always higher with high speed hammer type mill than with low speed roller or ball type mill. Generally speaking the low speed mills should be given preference for Illinois coal.

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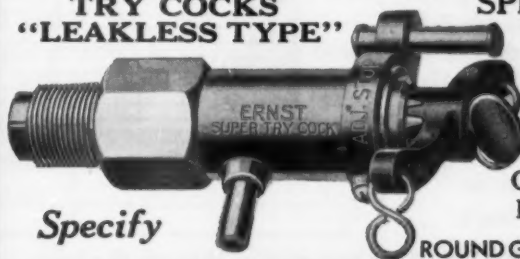


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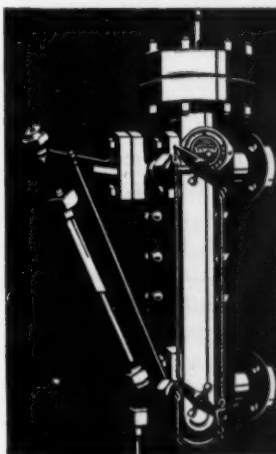
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As reported in the foreign technical press

Power Plant of the Normandie

The world's largest ship, the new 79,000-ton French liner "Normandie" has just made her maiden trip across the Atlantic in the record time of four days eleven hours. Aside from her size, the Normandie has the distinction of being the first turbine-electric propelled passenger ship in the trans-Atlantic service, although several American built passenger vessels in inter-coastal service and several U. S. battleships are so equipped.

Designed for a speed of 30 knots, the Normandie has four main turbine-generators of 33,400 kw each and six auxiliary sets aggregating 13,200 kw, making a total of 146,800 kw as the capacity of the power plant. Each of the four propellers is driven by a 40,000-hp motor. This power is less than that of the Cunard liner "Queen Mary" which has four 50,000-kw geared turbines for the main drive and approximately the same speed. The difference in power requirements, according to the *Engineering and Boiler House Review* for May, is due largely to the stream-lining of the hull and super-structure of the French ship.

Steam is furnished by twenty-nine oil-fired main boilers of the three-drum V type operating at 400 lb pressure and 680 F temperature and four auxiliary boilers designed for 142 lb per sq in. The auxiliary boilers furnish steam for various services and also provide make-up feedwater for the main boilers.

Large Velox Generators

At the Oslo Power Station, which is a steam reserve for a hydro system, there are being installed two 165,000 lb per hr oil-fired Velox steam generators designed to operate at 385 lb per sq in. and 800 F. These will supply steam to a 30,000-kw turbine-generator. Space limitations in an existing building and ability to start up from cold in a few minutes were deciding factors in selecting this type of boiler—*The Steam Engineer*, May 1935.

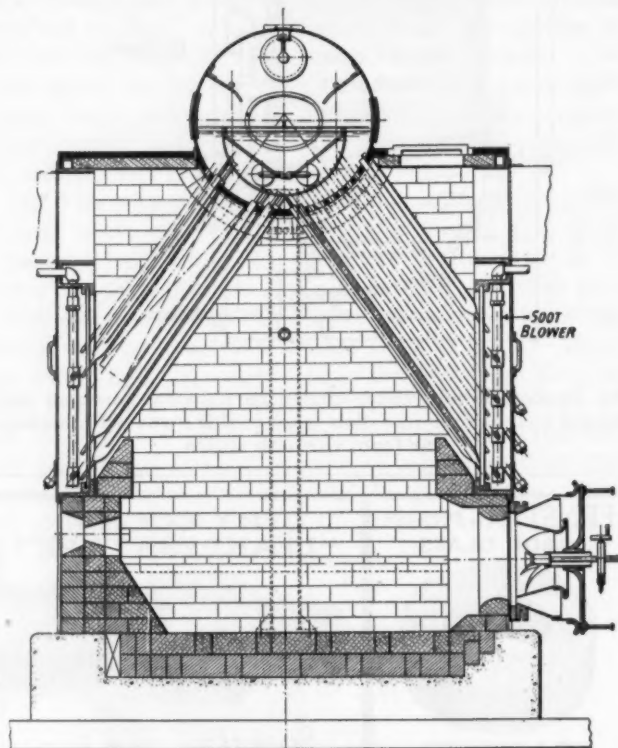
Single-Drum Boiler with U-Tubes

The Power Engineer (London) for May 1935 describes a new design of water-tube boiler invented by W. Y. Lewis, an installation of which has recently been made at the Northampton Polytechnic Institute.

Referring to the sectional elevation it will be seen that the design follows in general arrangement that of the well-known Yarrow straight-tube type, but that the bottom drums are omitted and tubes are in the form of a U. That is, the lower ends of each pair of tubes are welded together, as in a superheater. Extending down in these tubes are smaller tubes. The circulation is downward

through these inner tubes and a longitudinal partition in the bend provides for upward circulation in the opposite tube.

Proper circulation is further insured by the system of baffling within the boiler drums. The U-tubes discharge



Cross-section through the Lewis single-drum, U-tube boiler

their steam into a space formed between the drum and a semi-cylindrical baffle, whereas the inner pipes pass through this baffle and draw their supply from a region of steam-free water.

The principal advantages claimed for this design are savings in weight and cost.

Continental Turbines

An interesting turbine unit is described in the January-February issue of *The Brown Boveri Review*. It is a combination of a high-pressure turbine and an extraction back-pressure turbine, arranged in tandem on the same shaft, with the latter used to heat the feedwater for both the high-pressure and the low-pressure boiler plants. The station in which it is installed has new 1335-lb boilers as well as old boilers generating steam at 270-lb gage. The high-pressure turbine takes 280,000 lb of steam per hour from the new boilers and exhausts at about 270 lb to the old low-pressure steam lines of the station. The

extraction turbine takes 40,000 lb. of steam per hour at 270 lb and exhausts at 40-lb gage with extraction at 125 lb. Feedwater heating is carried out with steam at 40 and 125 lb for the old plant and 40, 125 and 270 lb for the high-pressure boilers.

Commenting upon continental turbine practice, the same article states that in view of present reduced coal prices and limited capital available for new plant equipment there is a demand for cheaper machines despite somewhat lower efficiency. This has led to a more general demand for single-cylinder turbines especially for moderate steam pressures up to 350 lb gage and where base load operation is not involved. For pressures of 650 lb and higher the multi-cylinder machine must be used.

Operating with Steam-Benzol Mixture

There has been in operation for some time at the mills of H. W. Lange & Co., Altona, Germany, a most unusual power plant in which superheated steam from the primary boiler is passed through coils in a secondary boiler containing a mixture of water and benzol. This mixture when evaporated is used in both a small reciprocating engine and a 750-kw turbine, both operating condensing. Results of tests conducted last fall are reported in the May 1935 issue of *The Steam Engineer* and show a net saving of 24.16 per cent in the heat consumption of the turbine at 200 kw output when running on the mixture of steam and benzol instead of superheated steam alone. If the turbine had been operated with the same volume of mixed vapor as of steam, the output would have been 470 kw and the saving in heat 37 per cent.

With the reciprocating engine a gain in thermal efficiency of 42 per cent was shown when using the mixture, although the Carnot efficiency was only 14.45 per cent compared with 15.41 for superheated steam alone. A full report of the turbine tests will appear in the June issue of *The Steam Engineer*.

Steam Condition Indicator

Some processes require a uniform temperature such as can be maintained with saturated steam at a given pressure. If the steam supply is taken from a superheated steam source and desuperheated, surveillance of the temperature becomes necessary. In order to enable the attendant to recognize at a glance whether the vessel contains saturated or superheated steam a combined pressure and temperature gage has been devised in Germany by the firm of Shaeffer & Budenberg and is described in the May issue of *Engineering Progress* (a V.D.I. publication).

The dial is made with a combination scale of steam pressures and equivalent saturation temperatures. As long as the steam in the vessel is saturated, the two pointers are coincident, but as soon as the steam becomes saturated the pointers diverge.

(Continued on page 36)

COMBUSTION—June 1935

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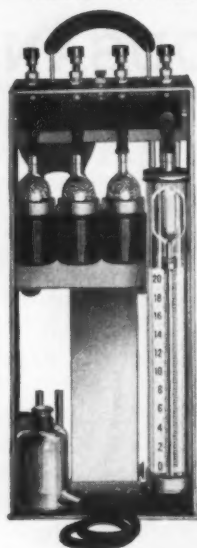
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British Stations Average 1.58 lb per kw-hr

The 1934 Report of the Electricity Commissioners (Great Britain) shows that during the year twenty-nine of the less efficient stations were shut down and four new ones started. The total electricity generated by steam (267 stations) was 16,138,402,713 kw-hr at an average coal consumption per kilowatt-hour of 1.58 lb, as compared with 1.65 lb for the preceding year. The most economical station from the standpoint of fuel consumption, was Battersea with 1.06 lb per kw-hr attained with a load factor of 53.7 per cent. Barking "B" Station (London) had the highest thermal efficiency, namely, 27.95 per cent, and Clarence Dock Station (Liverpool) was second with 26.82 per cent.

The following tabulation taken from the May issue of *The Fuel Economist*, London, gives the coal consumption per kilowatt-hour, the thermal efficiencies and the load factors of forty-two of the leading stations. It is significant that over half the total output was generated in twenty-five of the most efficient stations and nearly a quarter more in twenty-eight other stations. Thus, one-fifth of the stations accounted for three-quarters of the total output, which explains the low average coal consumption per kilowatt-hour, despite the fact that the least efficient group of small stations averaged 6.35 lb per kw-hr. Oil engine stations declined both in number and in output during the year.

Name of Station	Coal lbs. per Unit	Th. effi- ciency %	Load Factor %
Barking—B	1.09	27.95	51.7
Battersea (L.P. Co.)	1.06	27.24	53.7
Clarence Dock	1.09	26.82	78.5
Ironbridge	1.40	26.12	45.9
Dunston—B	1.22	25.35	47.9
Blackburn Meadows (New)	1.14	24.86	67.5
Thornhill	1.21	24.39	39.3
Deptford West	1.29	23.99	47.6
Spondon	1.38	23.86	45.0
Kearsley	1.18	23.70	55.6
Hams Hall	1.27	23.41	55.2
Kirkstall	1.36	23.21	48.3
Brimsdown—B	1.38	23.07	36.9
Hackney	1.35	22.62	41.3
Portishead	1.11	21.85	43.2
Portobello	1.47	21.83	39.5
Ferrybridge	1.37	21.79	65.8
Barton	1.31	21.74	49.0
Barking—A	1.41	21.67	34.1
Lots Road	1.41	21.42	44.6
Brighton	1.32	20.95	41.5
North Tees	1.38	20.91	39.7
Neasden	1.32	20.89	36.7
Stalybridge (Hartshead)	1.44	20.77	32.8
Lister Drive (No. 3)	1.47	20.77	42.0
Croydon	1.45	20.76	41.6
Chadderton	1.43	20.63	32.2
Yoker	1.42	20.38	37.9
Hull (Sculcoates)	1.60	20.37	36.8
Longford	1.72	20.02	29.4
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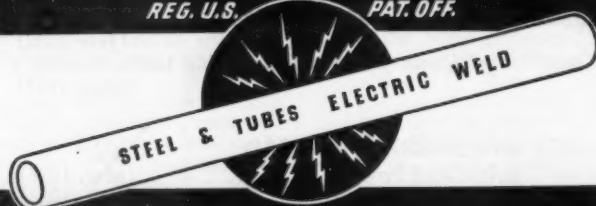
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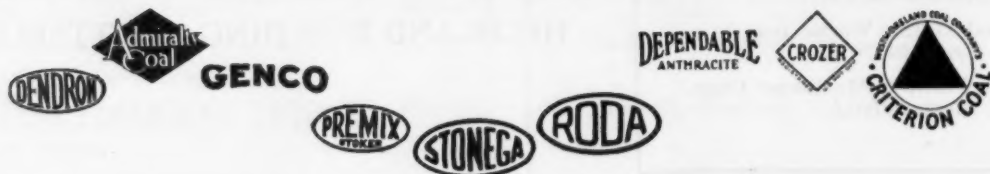
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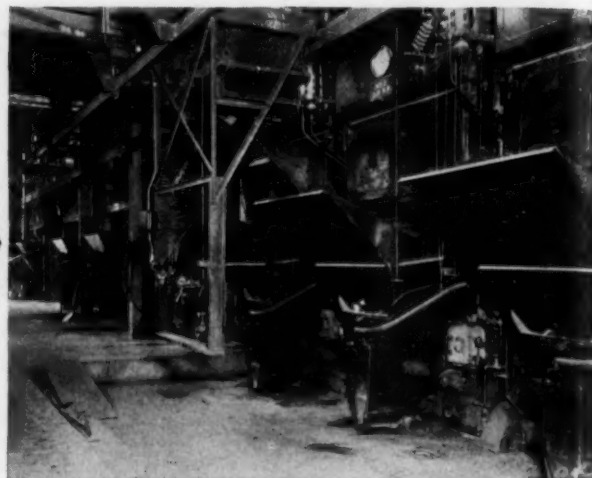
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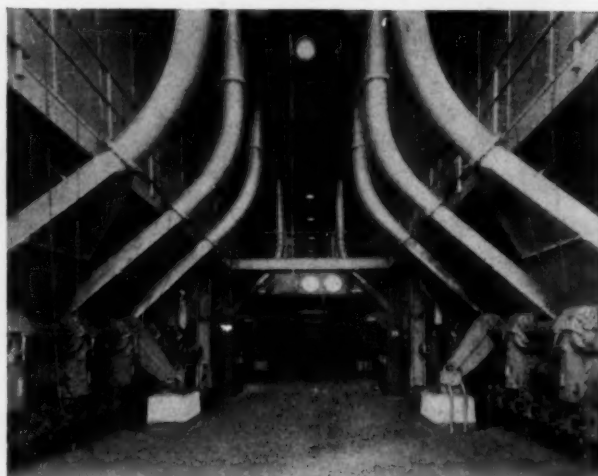
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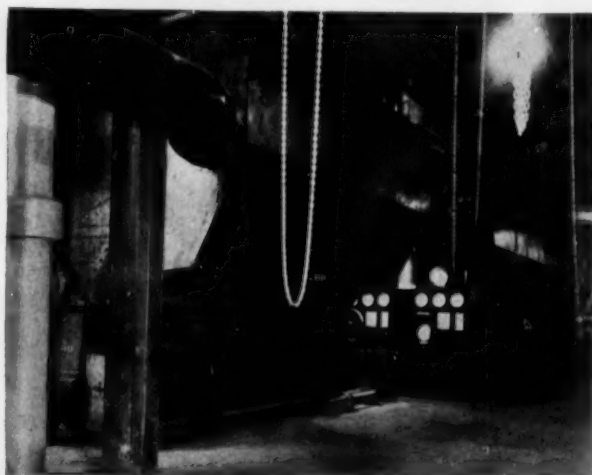
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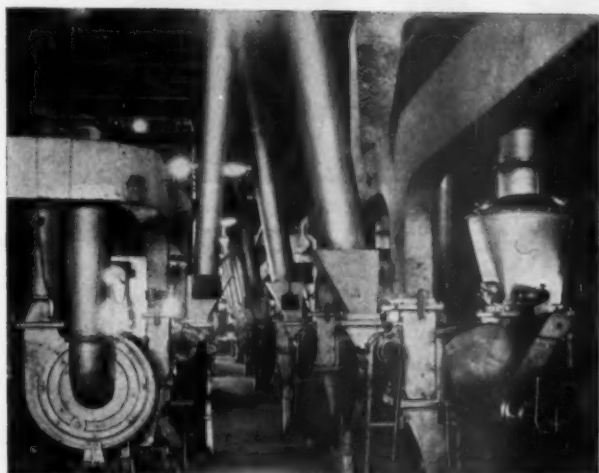
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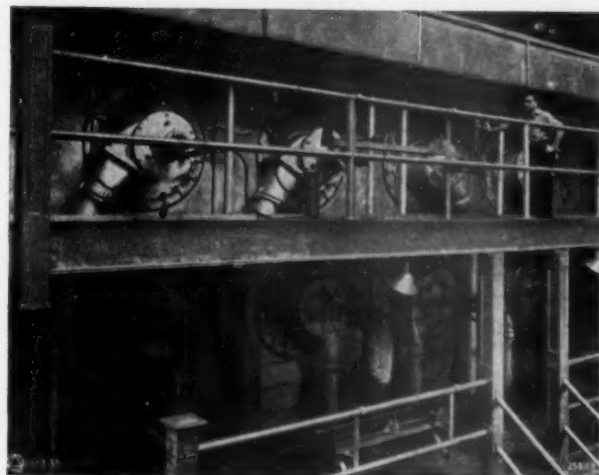
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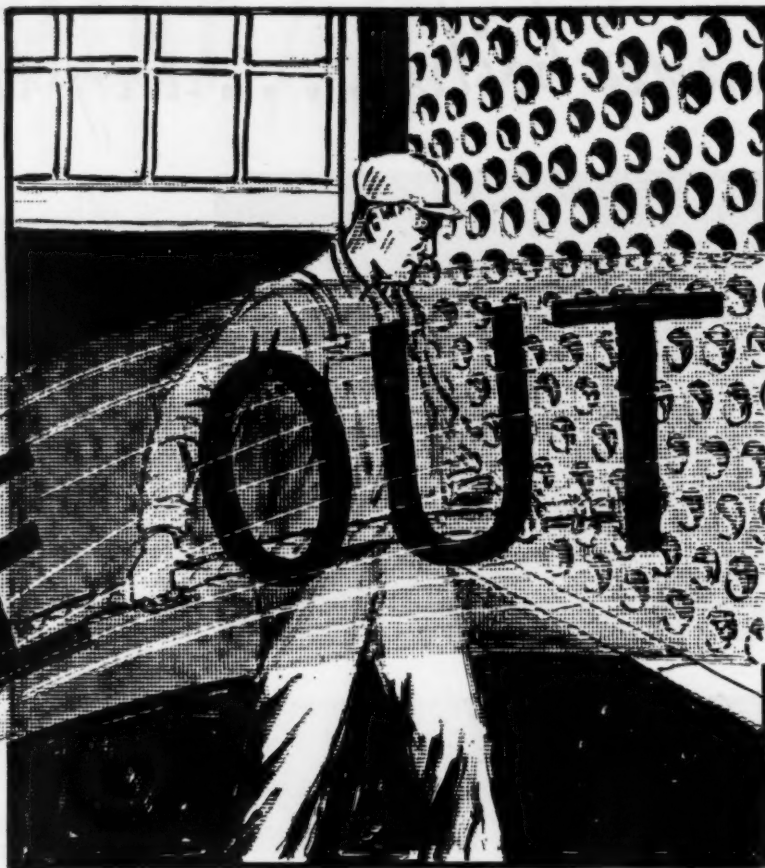
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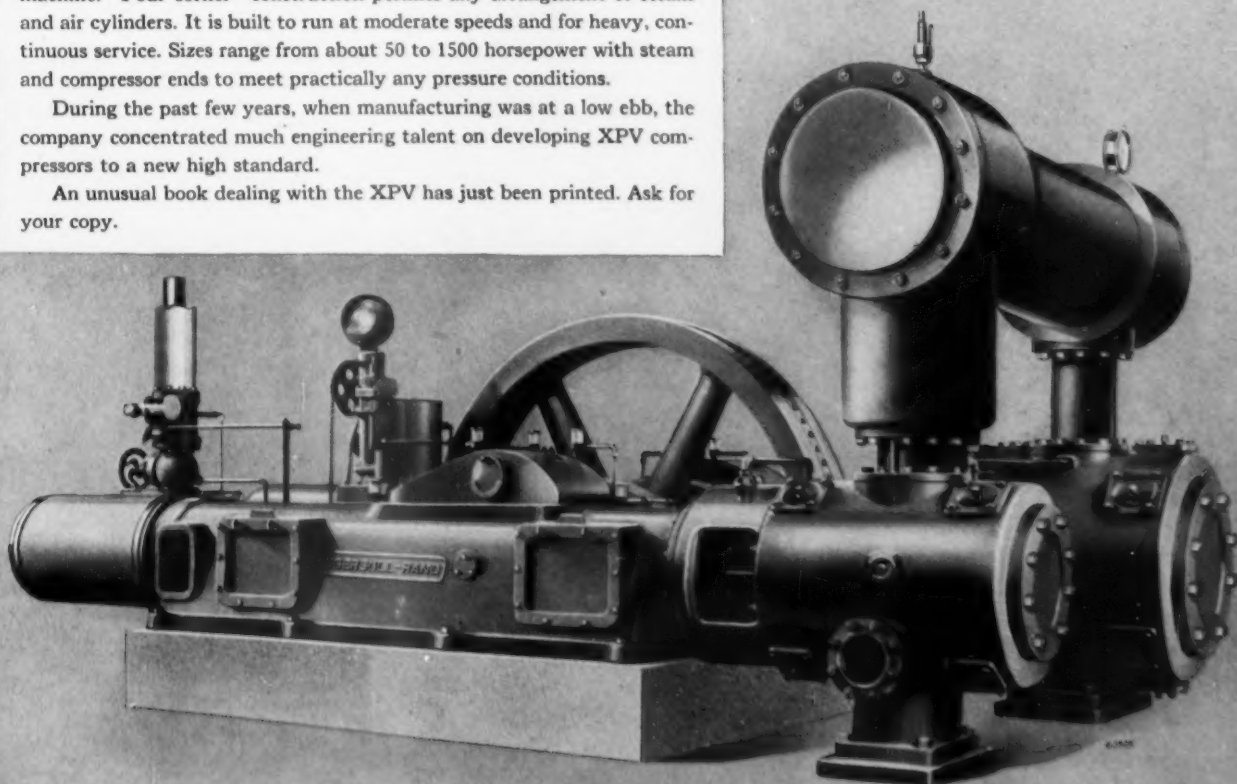
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LOWER STEAM, LIGHT AND POWER COSTS WITH BARTLETT-SNOW WEIGH LARRIES



THEIR boiler rooms equipped with Bartlett-Snow weigh larries, plant operators are in a position to keep accurate records of the operating efficiency of each boiler. Ideal combustion is secured.

Coal discharged from a fixed chute segregates. Fines remain in the center—lumps seek the sides. Uneven passage for the air and uneven drafts result. Gases burn hottest on the sides, scoring the side walls and burning out the stoker.

Bartlett-Snow weigh larries correct this condition. The operator records the weight in permanent form on a card, opens the chop gate, and moves the weigh larry back and forth. Segregation is eliminated. Steam costs and maintenance charges go down. Operating efficiency goes up.

Full details of Bartlett-Snow Special and Standard $\frac{1}{2}$, $\frac{3}{4}$, 1, and 2 ton weigh larries are available on request—or send for bulletin No. 73. It describes all types. No obligation.

THE C. O. BARTLETT & SNOW COMPANY
6208 HARVARD AVENUE CLEVELAND, OHIO

BARTLETT-SNOW

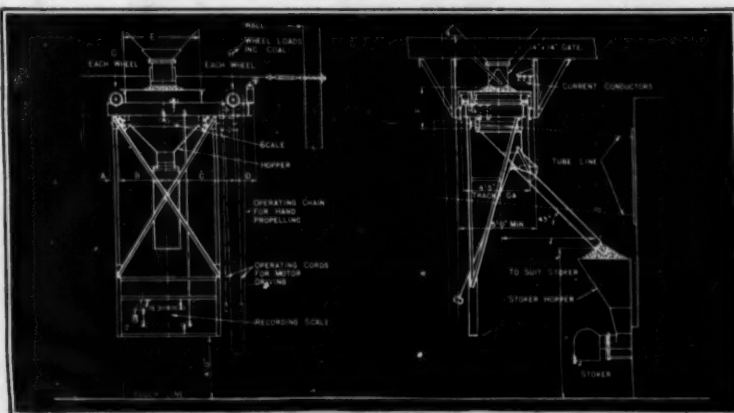
Coal and Ash

For { COAL: Skip hoists, bunkers, weigh larries
ASHES: Ash hoppers, skip hoists, bunkers
Complete coal and ash handling systems

HANDLING EQUIPMENT

EXECUTIVES DESIGNERS CHIEF ENGINEERS

Send for a copy of the new Boiler Plant Bulletin No. 73. 44 pages complete with 44 diagrams, 12 tables, 90 illustrations, describes the Bartlett-Snow method of securing less costly—more efficient operation. No obligation. Write today.



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